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Dr. H. H. Thomas, Code 922
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

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Dear Dr. Thomas:

Please find enclosed eight (8) copies of our Final Report, "Remanent Magnetization and Three-Dimensional Density Model of the Kentucky Anomaly Region". This delivery completes all requirements under the referenced contract.

Very truly yours,

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Ronald H. Estes
Project Manager

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REMANENT MAGNETIZATION AND THREE-DIMENSIONAL DENSITY MODEL OF THE KENTUCKY ANOMALY REGION

by

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Final Report

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TABLE OF CONTENTS

1.0 INTRODUCTION

Over the course of the Magsat project there has been much debate about the importance of large-scale remanent magnetization in the crust of the continents, and speculation about whether Magsat data can detect the phenomenon if it exists. These questions were the subject of the present investigation.

Magnetic anomaly maps derived from Pogo data (Regan et al, 1975; Mayhew, 1982) and Magsat data (Langel et al, 1982; Mayhew and Galliher, 1982) show a prominent anomaly over Kentucky and Tennessee (Figure 1). Equivalent layer magnetization models derived by inversion of such data (e.g. Mayhew and Galliher, 1982) indicate an extremely magnetic source region centered in Kentucky (Figure 2). The size of the magnetization anomaly suggests that this is the most important large-scale concentration of magnetic material in the crust of the continental U.S., yet there is no obvious direct expression of the source at the surface.

Mayhew et al (1982) found that a prominent elongate gravity anomaly occurs at the center of the source region indicated by magnetization models based on satellite data. A long wavelength aeromagnetic anomaly is directly associated with the gravity anomaly, although its form is largely masked by local near-surface magnetic anomalies. Using limited crustal seismic refraction data for constraint, the above authors produced a simple model, represented as two dimensional cross-sections, which accounts for the gravity and associated aeromagnetic anomalies. The model is in the form of an elongate body which is anomalously dense and magnetic extending through most of the thickness of the crust. On the basis of several lines of evidence, it was interpreted as a large mass of mafic intrusive rock of late Precambrian age, and was termed the "Kentucky body". Keller et al (1976) considered the gravity high to be part of a more extensive belt which they termed the "East Continent Gravity High", and interpreted as the expression of a late Precambrian rift zone.

For the first part of this study a three-dimensional model of the Kentucky body was developed to fit surface gravity and long wavelength aeromagnetic data. Magnetization and density parameters for the model are much like those of Mayhew et al (1982). The magnetic anomaly due to the model at satellite altitude is shown to be much too small by itself to account for the anomaly measured by Magsat. It is demonstrated that the source region for the satellite anomaly is considerably more extensive than the Kentucky body *sensu stricto*. The extended source region is modeled in the second part of the study, first using prismatic model sources and second using dipole array sources. Magnetization directions for the source region found by inversion of various combinations of scalar and vector data are found to be close to the main field direction, implying the lack of a strong remanent component. It is shown by simulation that in a case (such as this) where the geometry of the source is known, if a strong remanent component is present its direction is readily detectable, but by scalar data as readily as vector data.

2.0 LOCAL MODEL OF KENTUCKY BODY

Figure 3a is a local Bouguer gravity anomaly map for the area of the Kentucky body, while Figure 3b is the aeromagnetic map for the corresponding area. Figure 4 is the outline of a vertical-sided prismatic model body constructed to produce gravity and magnetic anomalies giving a gross fit to those observed. The model is divided into three parts. The top of the main (central) part is placed at 6 km below sea level; constraint for this is the refraction line of Warren (1968). The bottom is poorly constrained, but is placed at 42 km depth, about 8 km beneath the local Moho, giving a negative density contrast for this section which may account for the negative side-lobes in the computed gravity (Figure 5). The central body is approximately in isostatic equilibrium. The refraction line of Borcherdt and Roller (1966) extending across the south end of the gravity high indicates an abrupt drop in depth to the anomalous body from 6 km in the central part to 16 km in the southern part. This was used as a constraint on depth to top for the southern part of the model body. Calculations suggest that the southern part does not extend as deep below the local Moho as the central part, but there is no good constraint on this. For the final model, bottom was taken to be at Moho depth. The form of the north end of the gravity anomaly suggests a deepening of the top of the source. The Irvine-Paint Creek fault zone bounds the gravity anomaly on the north. Faulting is down-dropped to the north, consistent with the above inference. It is assumed that depth to the top of the body is 16 km, as in the south; this is consistent with the cross-section of Ammerman and Keller (1979) just to the east. Bottom is taken to be at Moho depth. The margins of the model body were placed by trial and error, using the gravity gradients as a guide, until a reasonably good fit was obtained. No attempt was made to fit the surrounding anomalies, for which there are no constraints. While there is not enough information to constrain the details of the geometry of the source, the gross geometry and density are well determined.

In modeling the source, the body was first constructed to fit the gravity anomaly (Figure 5) using Plouff's (1976) algorithm. Then the assumed magnetization for the body was found such that the computed magnetic anomaly amplitude was in agreement with the long wavelength part of that observed

(Figure 6). Again, it is not possible to fit the detailed local anomalies, but the mean magnetization of the model body itself (5.2 A/m) is well determined, certainly within 10%. Magnetic model computations also used Plouff's approach.

Finally, the magnetic anomaly due to the Kentucky body at satellite altitude (325 km) was computed, using the inferred magnetization value (Figure 7). Clearly, the computed anomaly is too small by a factor of about three to account for the observed anomaly (Figure 1).

3.0 REGIONAL MAGNETIZATION MODELS

The reason why the Kentucky body in itself cannot be the sole source of the satellite observed magnetic anomaly can now be easily seen from the recently-published aeromagnetic map of the U.S. (Zietz, 1982). This map shows clearly that the magnetic source region is considerably more extensive than the Kentucky body itself. An indication of the extent of this region is indicated in Figure 8. The relation of the Kentucky body itself in relation to regional tectonic elements can be seen in Figure 9. The extended source region was modeled in two ways, first using prismatic sources, and second using an array of dipole sources.

Examination of the U.S. aeromagnetic map indicates that the eastern mid-continent is a regionally magnetic high area relative to the eastern seaboard region. The gradient separating the two regions is a long straight zone known as the New York-Alabama lineament (King and Zietz, 1978), which passes just to the east of the Kentucky body. Expression of this lineament is present in the U.S. magnetization map (Figure 2), although it is distorted by the presence of the Kentucky source region.

In our modeling we assumed three simple regions, the first and second regions representing those parts to the northwest and southeast, respectively, of the New York-Alabama lineament, the third representing the extended Kentucky source region itself. The purpose of modeling the first and second regions along with the Kentucky region was to remove, to the extent possible, the biasing effect due to the difference in level between the first two regions.

3.1 Prismatic Models

These models used the formulation of Plouff (1976) for the magnetic anomaly due to vertical polygonal prisms. Prisms were arbitrarily made 40 km thick, i.e. comparable with the thickness of the whole crust, like the Kentucky body model described in Section 2.0. Calculations with these models involve an inherent flat-earth assumption, but for the limited area considered

differences with more rigorous spherical-earth models are very minor. For the area treated, three polygonal prismatic model sources were used. Two of the prisms are very large and have a common boundary, which is the New York-Alabama lineament (Figures 10-12). The third prismatic element is intended to model the extended source region of the Kentucky anomaly. This third region was modeled in three different ways; these are indicated by the blackened areas of Figures 10-12. The first model (Figure 10) represents the most restricted geographic source area, corresponding to the highest amplitude anomalies seen in the U.S. aeromagnetic map. It is actually two small, separate, but nearby, sub-regions which collectively give rise to a single observed anomaly. The second model (Figure 11) represents the largest area which can reasonably bound the Kentucky source region, again based on the U.S. magnetic anomaly map. The third area (Figure 12) is somewhat more restricted in area than the second, and probably represents the most realistic estimate of the boundaries of the source region, in as much as it avoids the linear anomalies on the east which are directly associated with the New York-Alabama lineament, rather than the Kentucky source region.

With the source geometries thus defined, a series of computer runs were made in which various combinations of vector component and scalar data from an equivalent source reduction of Magsat data (Figure 1) were inverted to magnetization solutions for the three regions (two large, one small), and for the largest and smallest geometries described above for the Kentucky source region. Two types of solutions were obtained. In the first, magnetization directions were constrained to be coincident with the main field direction ("induced" magnetization), and magnitudes only were solved for. In the second, magnetization directions were left unconstrained, and solutions were found for the magnetization components; this constituted a test for remanence. Results for a selection of key runs are summarized in Tables 1 and 2. These are for 1) input scalar data only, 2) input vector data only, 3) input both scalar and vector data.

Solutions for the two large source regions are not considered particularly significant, but it is noted that the second region (southeast) is generally more negative than the first (northwest), whether in magnitude or in vector orientation, so that incorporation of the two regions in the solutions seems to have accounted for some of the regional bias.

Solutions for the third (Kentucky source) region are quite consistent within each geometry. For the small geometry (Table 1, Figure 10) the magnetization vector magnitude for constrained and unconstrained cases falls between 7 and 9 A/m, the values being somewhat higher for the unconstrained case. For the unconstrained case, the angle between the magnetization vector and the main field direction varies from 7 ± 1 degrees to 14 ± 2 degrees, which is not significantly different from the main field direction. While the statistics are somewhat better where vector data is input, this may simply be the result of effectively using more data.

For the case of the larger, more detailed, prism (Table 2, Figure 11), angles between the magnetization vector and the main field direction for the unconstrained case are quite similar to those for the simple geometry. Source volume is larger so we expect magnetization values to be smaller; they fall in the range 3 - 3.5 A/m.

The anomaly in the total field for the "best" solutions for the Kentucky source region of Figure 11 alone for both constrained and unconstrained cases was computed at the altitude of the input data set, 325 km (Figures 13 and 14, respectively). The anomalies are dipole-like, with slightly different orientations. Note the low on the north side of each anomaly. The position of the low is in better agreement with the position of a low seen in the same area in the input anomaly data (Figure 1) for the constrained case than for the unconstrained case. This perhaps adds some support to the idea that magnetization in the source region is by induction in the main field.

A single run was made for the third geometry for the Kentucky source region, with magnetization of the source constrained to lie in the main field direction. The magnetization solution for this geometry was 4.2 A/m. Note that this value is in good agreement with that determined for the Kentucky body (5.2 A/m) as described in Section 2.0. This is an interesting result, because it suggests that the depth extent for the whole of the extended source region is comparable with that of the Kentucky body, i.e. most of the crustal thickness. While there are no constraints on this thickness, and 40 km was

assumed in the models, the depth extent could not be much less without associated magnetization values becoming unreasonably large. The anomaly in the total field (ΔB) due to this geometry for the Kentucky source region alone is show in Figure 15. When this is subtracted from the original input ΔB data (Figure 1), an anomaly data set free of the influence of the Kentucky source region should result. This is shown in Figure 16. The large "bull's-eye" (which is the "Kentucky anomaly" of Figure 1) is gone and the remaining smaller highs are interpreted to be associated with the New York- Alabama lineament.

Finally, as a check on detectability of remanence, we computed the magnetic anomaly due to the Kentucky source region alone with an assumed direction of magnetization 90° away from the main field direction, added it to the residual data set (Figure 16), and then attempted to recover the direction using the inversion program. The assumed direction was recovered exactly. Our interpretation of the above results corresponds to conventional wisdom: where the geometry of the source is reasonably well known, its magnetization vector can be found by least squares estimation using one or any combination of vector and scalar data types.

3.2 Dipole Array Models

These models utilized a new approach to spherical earth equivalent dipole modeling of regional sources by constraining all dipoles falling within specified regions to adjust together in a least squares solution. The method is referred to as mosaic dipole modeling in that a region of interest is divided into a set of mosaic subregions in which the dipole arrays are constrained. These mosaic subregions are specified by geologic structural considerations. A more detailed description of the method is given in Appendix A.

The purpose of utilizing two different approaches for our regional magnetization modeling is to provide greater credence and support for conclusions drawn from the resulting solutions. As with the prismatic models of Section 3.1, three mosaic regions were utilized to describe the area treated. The dipole grid array and the corresponding mosaic regions are displayed in

Figure 17. Regions I and II are large and have a common boundary approximated by the New York-Alabama lineament. Region III models the Kentucky body. To more closely correspond to the structure represented by the prism of Figure 10, the three dipoles comprising the Kentucky body were shifted slightly away from the grid points displayed in Figure 17. In particular, the western-most dipole was shifted .1° to the north and .4° to the east, the northern-most dipole was shifted .4° to the south and .5° to the east, and the remaining dipole was shifted .4° to the south and .4° to the east.

With this source geometry, a series of computer runs were made with the same combinations of data and solution types as described in Section 3.1. The results are presented in Table 3 and show a satisfying consistency with the results of the prismatic models. As with the prismatic models, the solutions for the two large mosaic regions are not considered significant, but do show the same more negative structure in the southeast mosaic. The solutions for the Kentucky body produce magnetization vector magnitudes very similar to those of Section 3.1, while the angle between the magnetization vector and the main field direction for the source component solutions varies from 14 ± 5 degrees to 17 ± 1 degrees.

4.0 CONCLUSIONS

Based on the results of the local model of the Kentucky body and the regional magnetization models, we reach the following conclusions:

1. The Kentucky body alone cannot account for the magnetic anomaly measured by Magsat.

2. The anomaly measured by Magsat can be accounted for by a more extensive magnetic source region defined by aeromagnetic data, with magnetization (4.2 A/m) comparable with that determined for the Kentucky body (5.2 A/m).

3. The magnetization value for the extended area suggests that magnetic material is distributed through most of the crustal thickness, as it is for the Kentucky body itself; however, a gravity anomaly is not associated with the extended source region.

4. The direction of magnetization determined for the extended source region is near the main field direction, suggesting that a strong remanent magnetization is lacking.

5. Where the geometry of the source is known, magnetization direction can be found by inverse methods, but equally well with scalar data as with vector data.

6. Results from dipole array modeling agree with results from prismatic source modeling; the two very different approaches provide a mutual check.

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APPENDIX A. MOSAIC DIPOLE MODEL

This technique represents a new method for regional magnetization modeling using a constrained dipole equivalent source approach. The method consists of using a spherical earth equivalent dipole source model with the dipoles within geologically specified mosaic regions constrained to adjust as a fixed entity (i.e. all dipoles within the region are constrained to the same magnitude and direction by mathematical equations). A least squares estimation algorithm best fits the anomaly data while adjusting the constrained dipole regions. The program will operate in two modes:

a) adjust source magnitudes with the directions forced to lie in the main field direction

b) adjust both source magnitudes and direction.

Data input to the software is any combination of ΔB_r , ΔB_θ , ΔB_ϕ or ΔB . The coordinate system utilized is the spherical $\hat{r}$, $\hat{\theta}$, $\hat{\phi}$ system.

The mathematical description of the least squares algorithm with the constrained mosaic regions is given in Appendx A.1, while the mathematical derivation of the dipole source function is presented in Appendix A.2. A description of program input is given in Appendix A.3, while a source listing is presented in Appendix A.4.

APPENDIX A.1 Least Squares Analysis with Constrained Regions

Suppose we are given the linear system

$$y = Ap + v \tag{A1.1}$$

where y is a vector of observations of dimension m, p is a vector of parameters of dimension n to be estimated, A is the $(m \times n)$ matrix of partial derivatives of the modeled observations with respect to the parameters, and v is a vector of observation errors of dimension m with zero mean, $E(v) = 0$. Then the least squares solution of $\hat{p}$ of Equation (A1.1) is chosen to minimize the square of the observation errors,

$$J(p) = (y-AP)^T (y-AP) = v^T v \quad . \tag{A1.2}$$

In the situation where observations of different noise characteristics are involved, a solution of the weighted least squared problem is desired which minimizes the quadratic function

$$J(p) = (y-Ap)^T W (y-Ap) \tag{A1.3}$$

where W is an $(m \times m)$ weight matrix. In our applications, the weight matrix is diagonal with elements equal to the inverse square of the observation noise sigma, σ,

$$W = E[vv^T]^{-1} = \begin{vmatrix} \frac{1}{\sigma_1}^2 & & & & \\ & \frac{1}{\sigma_2}^2 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \quad \frac{1}{\sigma_m}^2 \end{vmatrix}$$

A necessary and sufficient condition for a minimum of Equation (A1.3) is that its first variation be zero,

$$\delta J(p) = 0 \quad .$$

This leads directly to the system of normal equations

$$A^T WA \hat{p} = A^T Wy \tag{A1.4}$$

and to the least squares estimate

$$\hat{p} = (A^T WA)^{-1} A^T Wy \quad . \tag{A1.5}$$

The matrix $A^T WA$ of dimension (n x n) is called the information matrix. If in addition to the linear system (A1.1) we have an a priori estimate of p and an a priori information matrix denoted by $\hat{p}_0$ and Λ_0, respectively, then the normal equations become

$$(A^T WA + \Lambda_0) \hat{p} = A^T Wy + \Lambda_0 \hat{p}_0 \quad ,$$

so that

$$\delta\hat{p} = \hat{p} - \hat{p}_0 = (A^T WA + \Lambda_0)^{-1} A^T W[y - A\hat{p}_0] \quad . \tag{A1.6}$$

The set of measurements in our application consists of magnetic anomalies in the total field, ΔB, and anomalies in field components, F_r, F_Θ, F_ϕ at geographic positions i. We consider two different parameterizations of the anomaly field: (1) a set of ND dipoles of magnetization M_j

with their direction fixed along the main field, where

$$p = \begin{bmatrix} M_1 \\ M_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ M_{ND} \end{bmatrix}$$

and (2) a set of ND dipoles with components $(m_{r_j}, m_{\theta_j}, m_{\phi_j})$ where

$$p = \begin{bmatrix} m_{r_1} \\ m_{\theta_1} \\ m_{\phi_1} \\ m_{r_2} \\ m_{\theta_2} \\ m_{\phi_2} \\ \vdots \\ m_{r_{ND}} \\ m_{\theta_{ND}} \\ m_{\phi_{ND}} \end{bmatrix}$$

In the second case there are $3 \times ND$ parameters. Assume for the moment that there are no regional constraints so that all dipoles are independent. The parameter state vector p then contains all dipole parameters. Denoting the calculated $i^{\underline{th}}$ measurement as

$$F_i = a_{ik}\, p_k \tag{A1.7}$$

(summation convention assumed), it is readily seen that the elements of the matrix A are

$$A_{ij} = \frac{\partial F_i}{\partial p_j}\ , \tag{A1.8}$$

and represent the anomaly due to the $j^{\underline{th}}$ source at the $i^{\underline{th}}$ position for unit magnetization. The calculation of these source functions are described in Appendix A.2. The elements of the information matrix

$$\Lambda_{ij} = (A^T W A + \Lambda_o)_{ij} = \Lambda_{oij} + \sum_{\ell=1}^{m} W_{\ell\ell}\, \frac{\partial F_\ell}{\partial p_i}\, \frac{\partial F_\ell}{\partial p_j} \tag{A1.9}$$

and

$$\left[A^T W(y-y_o)\right]_j = \sum_{\ell=1}^{m} W_{\ell\ell}\, \frac{\partial F_\ell}{\partial p_j}(y-y_o)_\ell \tag{A1.10}$$

where

$$y_o = A\hat{p}_o \tag{A1.11}$$

are calculated and accumulated after processing each measurement.

Now consider that the set of dipoles specified by the state vector p are resident in a total of N regions $R_{j;j=1,N}$ and further let the vector P_j denote the parameterization of region R_j. If the option to force the dipoles along the main field direction is specified, P_j has a single element; otherwise, P_j has three independent components of magnetization. The total state vector now is P with element P_j and a total dimension of N (or 3*N) and should replace p in equations A1.1 through A1.6. The $i^{\underline{th}}$ measurement is now

$$F_i = \sum_{j=1}^{n} \left(\sum_{\ell_j} A_{i\ell_j}\right) P_j \tag{A1.12}$$

where the summation of ℓ_j is over all dipoles within region R_j. The elements of the matrix A in equations A1.8 through A1.10 now become

$$\bar{A}_{ij} = \frac{\partial F_i}{\partial P_j} = \sum_{\ell_j} A_{i\ell_j} \quad . \tag{A1.13}$$

Advantage is taken of the fact that Λ is a symmetric matrix so that only the upper triangular portion is accummulated. A Cholesky decomposition method is used to obtain the inversion of the information matrix, Λ^{-1}.

The estimate error covariance matrix is

$$C \equiv E[(\underline{P} - \hat{\underline{P}})(\underline{P} - \hat{\underline{P}})^T] = \Lambda^{-1} \tag{A1.14}$$

and the solution correlation matrix ρ is computed as

$$\rho_{ij} = \frac{C_{ij}}{\sqrt{C_{ii}\, C_{jj}}} \quad . \tag{A1.15}$$

The uncertainty in the computed angle Φ between the main field in region R_j and the magnetization vector P_j for region R_j may be obtained from the 3 x 3 submatrix C_j from C corresponding to region R_j . Let

$$\delta\Phi = B^T \delta P_j \tag{A1.16}$$

where

$$B_1 = \frac{1}{|P_j| \sin \Phi} \left(\frac{F_r}{F} - \cos \Phi \frac{P_{r_j}}{|P_j|} \right)$$

$$B_2 = \frac{1}{|P_j| \sin \Phi} \left(\frac{F_\theta}{F} - \cos \Phi \frac{P_{\theta_j}}{|P_j|} \right) \tag{A1.17}$$

$$B_3 = \frac{1}{|P_j| \sin \Phi} \left(\frac{F_\phi}{F} - \cos \Phi \frac{\partial P_{\phi_j}}{|P_j|} \right)$$

and F , F_r , F_θ , F_ϕ represent the main field magnitude and components in the center of region R_j . Then

$$\sigma_\Phi^2 = B^T C_j B \quad . \tag{A1.18}$$

The uncertainty in the magnitude $|P_j|$ may be obtained from equation A1.18 by replacing the vector B of equations A1.16 and A1.17 with

$$B_1 = \frac{P_{r_j}}{|P_j|}$$

$$B_2 = \frac{P_{\theta_j}}{|P_j|} \qquad (A1.19)$$

$$B_3 = \frac{P_{\phi_j}}{|P_j|} \quad .$$

APPENDIX A.2 SOURCE FUNCTION DERIVATION

In this section we derive the expressions for the anomaly components and the anomaly in the total field due to a dipole at the earth's surface. We use a spherical coordinate system (r, θ, ϕ), where r is radial distance out, θ is colatitude, and ϕ is longitude east. Let primed quantities refer to the location of a point dipole, unprimed quantities to an external position at which the magnetic field arising from the dipole is to be evaluated.

The magnetic potential at (r, θ, ϕ) due to a dipole source at (r', θ', ϕ') is

$$V = -\bar{M}' \cdot \nabla' (1/\ell) \quad , \tag{A2.1}$$

where ℓ is the distance betwen the source and the external point. $\bar{M}$ is the dipole moment, with components $(m_r , m_\theta , m_\phi)$. ℓ may be written

$$\ell = r^2 + r'^2 - 2rr' \cos \zeta)^{1/2}$$

where ζ is the central angle between the two positions. Then it is easy to show that

$$V = \{m_r(rA - r') - m_\theta rB + m_\phi rC\}/\ell^3 \tag{A2.2}$$

$$= V_r + V_\theta + V_\phi = V_1 + V_2 + V_3 \quad ,$$

where

$$A = \cos \theta \cos \theta' + \sin \theta \sin \theta' \cos (\phi - \phi') = \cos \zeta$$

$$B = \cos\theta \sin\theta' - \sin\theta \cos\theta' \cos(\phi - \phi') \qquad \text{(A2.3)}$$

$$C = \sin\theta \sin(\phi - \phi') \quad .$$

For future reference, write $A1 = A$, $B1 = B$, $C1 = C$.

Then the anomaly field vector is

$$F = -\nabla V = -\left\{\frac{\partial}{\partial r}, \frac{\partial}{r\partial\theta}, \frac{\partial}{r\sin\theta\partial\phi}\right\} V \quad . \qquad \text{(A2.4)}$$

We will need $\left\{\frac{\partial}{\partial\theta}, \frac{\partial}{\sin\theta\partial\phi}\right\}$ (A,B,C) .

They are

$$\frac{\partial A}{\partial\theta} = -\sin\theta\cos\theta' + \cos\theta\sin\theta'\cos(\phi - \phi') = A2$$

$$\frac{\partial B}{\partial\theta} = -\sin\theta\sin\theta' - \cos\theta\cos\theta'\cos(\phi - \phi') = B2$$

$$\frac{\partial C}{\partial\theta} = \cos\theta\sin(\phi - \phi') = C2 \qquad \text{(A2.5)}$$

$$\frac{\partial A}{\sin\theta\partial\phi} = -\sin\theta'\sin(\phi - \phi') = A3$$

$$\frac{\partial B}{\sin\theta\partial\phi} = \cos\theta'\sin(\phi - \phi') = B3$$

$$\frac{\partial C}{\sin\theta\partial\phi} = \cos(\phi - \phi') = C3 \quad .$$

Define the following quantities:

$$D1 = r - r'\,A1 \qquad F1 = rA1 - r'$$
$$D2 = -r'\,A2 \qquad F2 = -rB1 \tag{A2.6}$$
$$D3 = -r'\,A3 \qquad F3 = rC1$$

$$F_r = -\frac{\partial V}{\partial r}$$

$$= m_r\{3D1F1/\ell^2-A1\}/\ell^3 + m_\theta\{3D1F2/\ell^2+B1\}/\ell^3 + m_\phi\{3D1F3/\ell^2-C1\}/\ell^3$$

$$F_\theta = -\frac{\partial V}{r\partial\theta}$$

(A2.7)

$$= m_r\{3D2F1/\ell^2-A2\}/\ell^3 + m_\theta\{3D2F2/\ell^2+B2\}/\ell^3 + m_\phi\{3D2F3/\ell^2-C2\}/\ell^3$$

$$F_\phi = -\frac{\partial V}{r\sin\theta\partial\phi}$$

$$= m_r\{3D3F1/\ell^2-A3\}/\ell^3 + m_\theta\{3D3F2/\ell^2+B3\}/\ell^3 + m_\phi\{3D3F3/\ell^2-C3\}/\ell^3 \quad .$$

We now have equations for the components in the form

$$F_r = m_r\, d_{11} + m_\theta\, d_{12} + m_\phi\, d_{13}$$
$$F_\theta = m_r\, d_{21} + m_\theta\, d_{22} + m_\theta\, d_{23} \tag{A2.8}$$
$$F_\phi = m_r\, d_{31} + m_\theta\, d_{32} + m_\phi\, d_{33} \quad .$$

Then

$$\frac{\partial F_r}{\partial m_r} = d_{11} \qquad \frac{\partial F_r}{\partial m_\theta} = d_{12} \qquad \frac{\partial F_r}{\partial m_\phi} = d_{13}$$

$$\frac{\partial F_\theta}{\partial m_r} = d_{21} \qquad \frac{\partial F_\theta}{\partial m_\theta} = d_{22} \qquad \frac{\partial F_\theta}{\partial m_\phi} = d_{23} \qquad \text{(A2.9)}$$

$$\frac{\partial F_\phi}{\partial m_r} = d_{31} \qquad \frac{\partial F_\phi}{\partial m_\theta} = d_{32} \qquad \frac{\partial F_\phi}{\partial m_\phi} = d_{33} \quad .$$

The anomaly in the total field is

$$\Delta B = F_r \sin I + F_\theta \cos I \cos D + F_\phi \cos I \sin D \quad ,$$

where I and D are inclination and declination of the main field at the point of evaluations.

Thus,

$$\frac{\partial \Delta B}{\partial m_r} = d_{11} \sin I + d_{21} \cos I \cos D + d_{31} \cos I \sin D$$

$$\frac{\partial \Delta B}{\partial m_\theta} = d_{12} \sin I + d_{22} \cos I \cos D + d_{32} \cos I \sin D \qquad \text{(A2.10)}$$

$$\frac{\partial \Delta B}{\partial m_\phi} = d_{13} \sin I + d_{23} \cos I \cos D + d_{33} \cos I \sin D \quad .$$

The above partial derivatives are used to form the Jacobian matrix as described in Appendix A.1 for the case in which inversion of field measurements to vector sources is being attempted.

The formulation is different for the case in which source directions are fixed a priori and source magnitudes only are solved for. In this case, we write

$$F_r = M(\sin i)\ d_{11} + M(\cos i \cos d)\ d_{12} + M(\cos i \sin d)\ d_{13}$$

$$F_\theta = M(\sin i)\ d_{21} + M(\cos i \cos d)\ d_{22} + M(\cos i \sin d)\ d_{23} \qquad \text{(A2.11)}$$

$$F_\phi = M(\sin i)\ d_{31} + M(\cos i \cos d)\ d_{32} + M(\cos i \sin d)\ d_{33} \quad ,$$

where i and d are inclination and declination of the source. Then we form

$$\frac{\partial F_r}{\partial M} = d_{11} \sin i + d_{12} \cos i \cos d + d_{13} \cos i \sin d \quad , \qquad \text{(A2.12)}$$

and the other partials similarly. The anomaly in the total field is

$$\Delta B = F_r \sin I + F_\theta \cos I \cos D + F_\phi \cos I \sin D$$

$$= M[\sin I\{(\sin i)d_{11} + (\cos i \cos d)d_{12} + (\cos i \sin d)d_{13}\} \qquad \text{(A2.13)}$$

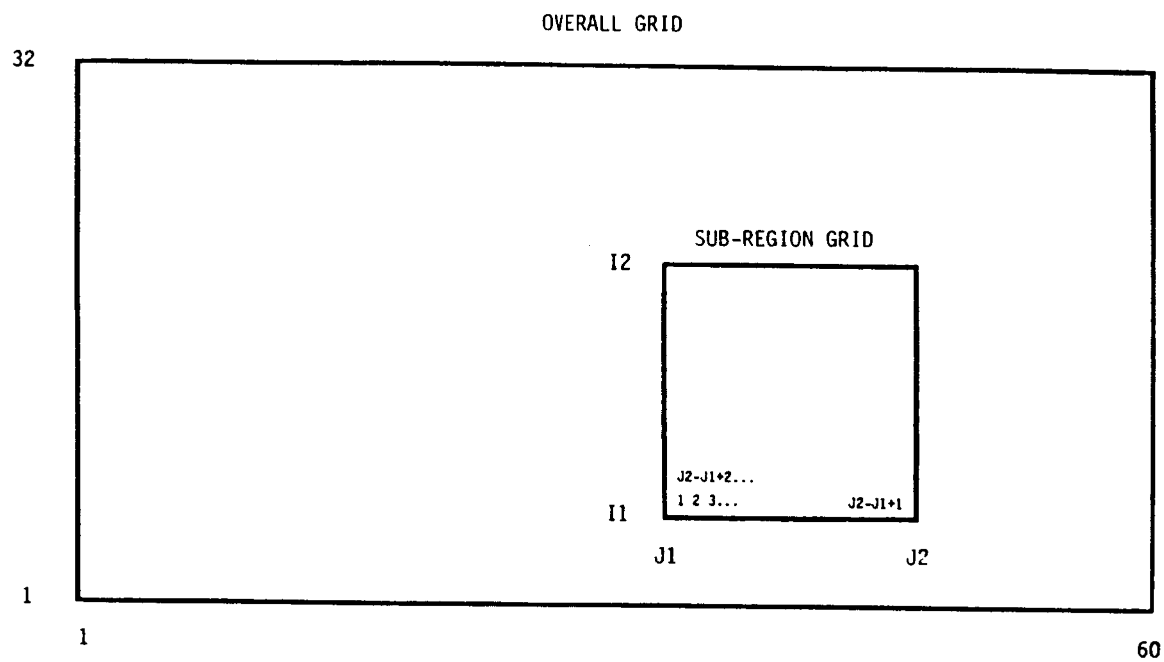
$$+ \cos I \sin D\{(\sin i)d_{21} + (\cos i \cos d)d_{22} + (\cos i \sin d)d_{23}\}$$

$$+ \cos I \sin D\{(\sin i)d_{31} + (\cos i \cos d)d_{32} + (\cos i \sin d)d_{33}\}]$$

from which we form $\partial \Delta B / \partial M$.

APPENDIX A.3 PROGRAM INPUT

Program input consists of a main field spherical harmonic model, an overall grid of dipole locations, data at the overall grid locations, parameters defining a selected sub-region of interest from the overall grid and the definition of the mosaic regions as subsets of the selected sub-region. The overall grid of dipole locations is a 60 x 32 array covering the U.S., and the selected sub-region of interest is identified by the parameters I1, I2, J1 and J2.



The program numbers the dipoles internally by proceding through the rectangular sub-region sequentially from left-to-right from bottom-to-top. <u>This is the numbered grid by which the user must define the mosaic areas.</u> The sub-region must be completely encompassed by mosaic regions, but a particular mosaic region need not be simply-connected. As an example, consider the 16 x 16 sub-region shown in Figure A.3.1. The Region I mosaic is defined by a sequence of entries giving the beginning column number, the number of columns, and the row number for each contiguous row segment. For example, Region I is identified by

Beginning Column No.	No. of Columns	Row No.
1	11	1
1	10	2
1	7	3
1	4	4
1	4	5
1	4	6
1	4	7
1	7	8
2	6	9
4	3	10
9	1	10
4	3	11
9	2	11

The program will also expect the total number of entries for defining the mosaic region to be given.

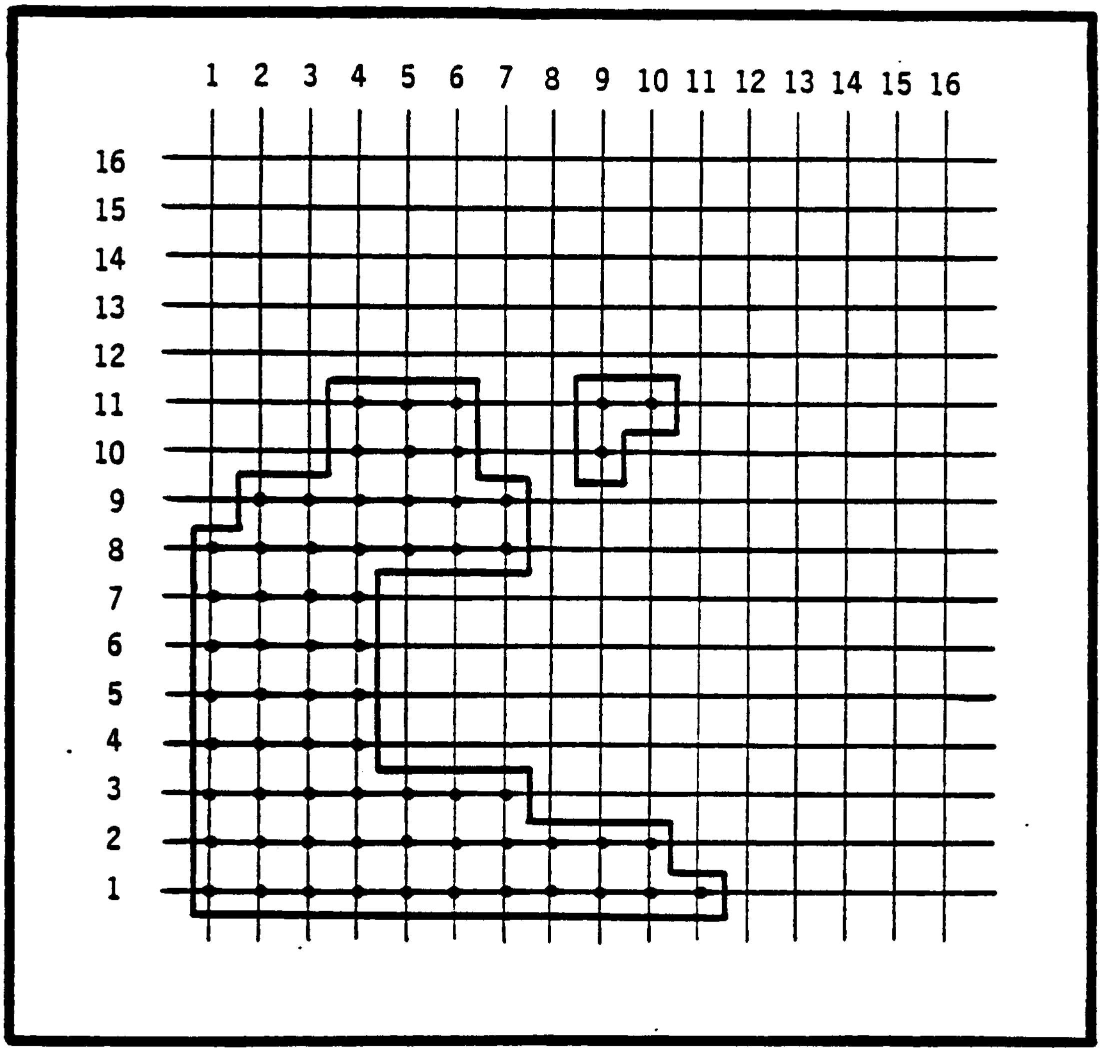


Figure A.3.1 Sample sub-region grid showing a mosaic region definition.

Program Control Variables

For the most part, the software is controlled by variables defined internally in data statements. In the main program, the following variables are set:

JOPT =	0	estimate source components
	1	estimate source magnitude only
L1 =	0	do not process ΔB_r data
	1	process ΔB_r data
L2 =	0	do not process ΔB_θ data
	1	process ΔB_θ data
L3 =	0	do not process ΔB_ϕ data
	1	process ΔB_ϕ data
L4 =	0	do not process ΔB data
	1	process ΔB data

Moreover, the variable NDIM is set which is the dimension of the upper symmetric portion of the normal matrix. Note that this value must be at least as large as required by the problem to be estimated and the array D must be dimensioned to at least this value.

In Subroutine FUN, the following variables are set:

I1 — the grid number of the overall grid which defines the lower latitude of the selected sub-region.

I2 — the grid number of the overall grid which defines the upper latitude of the selected sub-region.

J1 the grid number of the overall grid which defines the western longitude of the selected sub-region.

J2 the grid number of the overall grid which defines the eastern longitude of the selected sub-region.

In Subroutine DATA, similar variables are set which define the sub-region over which data will be processed. Note that the data sub-region need not be the same as the dipole sub-region.

Program Input Units

Data input to the program is accomplished on units 5 and 9. The unit 5 input is as follows:

a) Main Field Model in FDG format
b) Latitude and longitude locations of the overall grid (60 x 32)
c) ΔB data on a (60 x 31) grid
d) ΔX data on a (60 x 31) grid
e) ΔY data on a (60 x 31) grid
f) ΔZ data on a (60 x 31) grid

The unit 9 input is the set of entries read in Subroutine BLKS defining the mosaic regions via a 3I3 format. The data consists of the following:

a) The total number of Mosaic regions
b) The total number of entries for Mosaic Region 1
{the entries for Region 1 consisting of First Column Number, the number of columns, row numbers
c) Same as b) for Region 2

•

•

•

z) Same as above for the last mosaic region.

APPENDIX A.4 PROGRAM LISTING

```
//YCDMMCTR JOB (F8002,377,14),MOSAIC.DIPOLE,TIME=(01,00),NOTIFY=YCDMM,
//  CLASS=A
/*JOBPARM LINES=100
// EXEC OFORTH,PARM=XREF
//SOURCE.SYSIN DD *
      DIMENSION NUMEL(1920) , IELNUM(1920) , CDFDP(1920)
      REAL*8 CDFDP
       DIMENSION Q(5),SWT(5),SMEAN(5),SIG(5),RMS(5)
      DIMENSION DC(680),DCC(680)
      DIMENSION  D(500),DW(680),DP(680),SDD(3)
      COMMON/CP/ CP(680)
      COMMON/BLOKS/ NPCNTR,NDCNTR,IELNUM,NUMEL
          COMMON/DATAST/IDAT,IDUM,ICD,FRD,FTD,FPD
      COMMON/REC/RLAT(32),RLON(32),RLEV(32),DF(32),BR(32),BT(32),BP(32)
      COMMON/BWC/P(680),DFDP(680),DFDP1(680),DFDP2(680),DFDP3(680),
     * DFDP4(680),X(3),FR,FT,FP,YC,NP,ND
          COMMON/DMAT/D
          COMMON/DIPCLE/ALAT(226),ALON(226)
          COMMON/NDIM/NDIM
      REAL*8 D,DFDP1,DFDP2,DFDP3,DFDP4,DFDP,DW,DP,SUMD,DC,DCC
      DATA LAST,INII/0,0/,JCORPR/1/
      DATA L1,L2,L3,L4,JOPT,JCNSTR/1,1,1,1,0,0/
      DATA SIGDF,SIGBR,SIGBT,SIGBP/1.0,6.0,6.0,6.0/
          LOC(I,J,MDIM)=(J-1)*MDIM -(J**2-J)/2 + I
C   NDIM IS THE NUMBER OF ELEMENTS IN THE NORMAL MATRIX AND MUST THE
C              SAME OR LESS THAN THE DIMENSION OF THE ARRAY D
C     NDIM=NPARM*(NPARM+1)/2
C         WHERE NPARM IS THE NUMBER OF PARAMETERS ESTIMATED
          NDIM=500
C
      DO 422 I=1,680
      CP(I)=0.0
 422  CONTINUE
C SET DATA COMPONENT WEIGHTS
C
      SWTDF=1.0/SIGDF
      WTDF=SWTDF*SWTDF
      SWTBR=1.0/SIGBR
      WTBR=SWTBR*SWTBR
      SWTBT=1.0/SIGBT
      WTBT=SWTBT*SWTBT
      SWTBP=1.0/SIGBP
      WTBP=SWTBP*SWTBP
C
C SET UP SOURCE ARRAY
C
      CALL FUN2 (JOPT,JCNSTR)
C
C  IF SOLUTION IS FOR SOURCE COMPONENTS, COMPUTE ANGLE
C  BETWEEN A PRIORI AND MAIN FIELD
C
          IF(JOPT.EQ.1) GO TO 16
          DO 15 I=1,ND
          II=I
          CALL ANGL(ANG,II)
 15       CONTINUE
 16       CONTINUE
C
C SET UP DATA SET FOR INPUT
C
      CALL DATA2
C
C    JCORPR=0  NO PRINT FOR CORRELATION MATRIX
C    JCORPR=1  PRINT CORRELATION MATRIX
C
C JOPT=0 TO ESTIMATE SOURCE COMPONENTS
C JOPT=1 TO ESTIMATE SOURCE MAGNITUDES ONLY
C
C JCNSTR=0  NO CONSTRAINT
C JCNSTR=1  CONSTRAINED
C
C
C L1=1 TO INPUT RADIAL FIELD COMPONENT
C L2=1 TO INPUT SOUTH FIELD COMPONENT
C L3=1 TO INPUT EAST FIELD COMPONENT
C L4=1 TO INPUT ANOMALY IN THE TOTAL FIELD
C FUN RETURNS CORRESPONDING COMPUTED QUANTITIES
C
  25 FORMAT (4I5,I10)
```

```
C     CONTRACT DFDP VECTOR AS DICTATED BY CONSTRAINTS
C       DFDP IS THE ARRAY OF PARTIALS
C
C       SET UP THE MOSAIC REGIONS DEFINED IN TERMS OF THE INPUT GRID
C         OF DIPOLES
            CALL BLKS(NDCNTR,NUMEL,IELNUM)
C  NDCNTR IS THE NUMBER OF MOSAIC REGIONS
C   NPCNTR IS THE NUMBER OF INDEPENDENT PARAMETERS ESTIMATED
            NPCNTR=NDCNTR
            IF(JOPT.NE.1) NPCNTR=3*NDCNTR
C
C     PRINT A PRIORI COVARIANCE MATRIX
C           CALL CORLPE(D,DW,NPCNTR,0)
       DO 3 J=1,NDIM
   3        D(J)=0.D0
C
       NN=0
       MM=0
C      ZERO RIGHT HAND SIDE
       DO 2 J=1,NP
       DW(J)=0.D0
    2  CONTINUE
C
            DO 18 J=1,NP
            P(J)=0.D0
            CP(J)=0.
  18         CONTINUE
  19            CONTINUE
C
C
C  CALL FOR DATA PROFILE
C  NPTS POINTS AT POSITIONS (LATITUDE,LONGITUDE,ELEVATION)=(RLAT,RLON,
C   ELEV)
C
        WRITE(6,30)
  30    FORMAT(/1X,'INPUT DATA'//3X,'NO.',5X,'LAT.',5X,'LON.',6X,
      *'ALT.',13X,'BR',8X,'BT',8X,'BP',8X,'B'/)
    9  FORMAT (I5)
   39  CALL DATA (INIT,NPTS,LAST)
       DO 20 I=1,NPTS
       X(1)=RLAT(I)
       X(2)=RLON(I)
       X(3)=ELEV(I)
       CALL FUN (JOPT,JCNSTR)
       MM=MM+1
C
C  FORM RESIDUALS (OBSERVED-COMPUTED FIELD) DY FOR VARIOUS INPUT COMPS
C
       DO 79 L=1,4
       GO TO (71,72,73,77),L
   71  CONTINUE
       IF (L1.EQ.0) GO TO 79
       NN=NN+1
       DO 74 J=1,NP
   74  DFDP(J)=DFDP1(J)*SWTBR
       DY=(BR(I)-FR)*SWTBR
       GO TO 70
   72  CONTINUE
       IF (L2.EQ.0) GO TO 79
       NN=NN+1
       DO 75 J=1,NP
   75  DFDP(J)=DFDP2(J)*SWTBT
       DY=(BT(I)-FT)*SWTBT
       GO TO 70
   73  CONTINUE
       IF (L3.EQ.0)   GO TO 79
       NN=NN+1
       DO 76 J=1,NP
   76  DFDP(J)=DFDP3(J)*SWTBP
       DY=(BP(I)-FP)*SWTBP
       GO TO 70
   77  CONTINUE
       IF (L4.EQ.0) GO TO 79
       NN=NN+1
       DO 78 J=1,NP
   78  DFDP(J)=DFDP4(J)*SWTDF
       DY=(DF(I)-YC)*SWTDF
   70  CONTINUE
C
C
C      CONTRACT DFDP VECTOR TO DIMENSION NPCNTR AS DICTATED BY CONSTRAINT
C
       M1=1
```

```
      DO 165 J=1,NDCNTR
      M2=M1+NUMEL(J)-1
      IF(JOPT .NE. 1) GO TO 162
       CDFDP(J)=0.0D0
       DO 161 M=M1,M2
        CDFDP(J)=CDFDP(J) + DFDP(IELNUM(M))
161    CONTINUE
      GO TO 164
162   J3=3*(J-1)
      CDFDP(J3+1)=0.0D0
      CDFDP(J3+2)=0.0D0
      CDFDP(J3+3)=0.0D0
      DO 163 M=M1,M2
      M3=3*(IELNUM(M)-1)
      CDFDP(J3+1)=CDFDP(J3+1)+DFDP(M3+1)
      CDFDP(J3+2)=CDFDP(J3+2)+DFDP(M3+2)
      CDFDP(J3+3)=CDFDP(J3+3)+DFDP(M3+3)
163   CONTINUE
164   M1=M2+1
165   CONTINUE
C
C
C
C FORM DW (THE RHS VECTOR) AND D MATRICES
C
      DO 5 J=1,NPCNTR
      DW(J)=DW(J)+CDFDP(J)*DY
          LC=LOC(J,J,NPCNTR) - 1
          DO 5 M=J,NPCNTR
          LC=LC + 1
          D(LC)=D(LC) + CDFDP(J)*CDFDP(M)
 5     CONTINUE
 79   CONTINUE
      WRITE (6,7) MM,X(1),X(2),X(3),BR(I),BT(I),BP(I),DP(I)
  7   FORMAT (I5,2F10.2,F10.1,5X,4F10.2/)
 20   CONTINUE
      IF (LAST.EQ.0) GO TO 99
      IF (MM.LE.NPCNTR) GO TO 400
C
C  COMPUTE CHECK SUM COLUMN AND INVERT D MATRIX
C
          DO 6 L=1,NPCNTR
          SUMD=0.D0
          DO 4 M=1,NPCNTR
          LC=LOC(L,M,NPCNTR)
          IF(L.LE.M) LC=LOC(M,L,NPCNTR)
 4      SUMD=SUMD + D(LC)
  6        DC(L)=SUMD
           CALL TSINV(NPCNTR,NPCNTR,D,DFDP)
C
C FORM PARAMETER CORRECTION VECTOR DP FOR THE ESTIMATED PARAMETERS
C
      DO 530 J=1,NPCNTR
      DP(J)=0.
      DCC(J)=0.
      DO 530 K=1,NPCNTR
          LC=LOC(J,K,NPCNTR)
          IF(J.LE.K) LC=LOC(K,J,NPCNTR)
      DP(J)=DP(J)+D(LC)*DW(K)
          DCC(J)=DCC(J) + D(LC)*DC(K)
 530  CONTINUE
C  COMPUTE AND PRINT THE VECTOR CP OF ESTIMATED MOSAIC PARAMETERS
      WRITE (6,58)
 58       FORMAT(///'*** SOLUTION ***'///' ',9X,'P0',20X,
     *'CP',20X,'DP',18X,'CHECK',18X,'VAR',20X,'RATIO'//)
      DO 540 J=1,NPCNTR
          P0=CP(J)
      CP(J)=CP(J)+DP(J)
          LC=LOC(J,J,NPCNTR)
          VAR=DSQRT(D(LC))
       DC(J)=D(LC)
          RATIO=VAR/CP(J)
          WRITE(6,53) J,P0,CP(J),DP(J),DCC(J),VAR,RATIO
  53       FORMAT (I4,6D20.8)
 540  CONTINUE
C
C
C      EXPAND OR UN-CONTRACT MOSAIC PARAMETER ( P ) VECTOR INTO DIPOLE P
C         PARAMETER VECTOR THAT INVERSION IS OVER SO RESIDUALS
C         MAY BE CALCULATED .
C
      M1=1
      DO 565  J=1,NDCNTR
```

```
      M2=M1+NUMEL(J)-1
        IF(JOPT .NE. 1) GO TO 562
        DO 561 M=M1,M2
          P(IELNUM(M))=P(IELNUM(M))+CP(J)
561     CONTINUE
      GO TO 564
562     DO 563 M=M1,M2
         M3=3*(IELNUM(M)-1)
         J3=3*(J-1)
         P(M3+1)=P(M3+1)+CP(J3+1)
         P(M3+2)=P(M3+2)+CP(J3+2)
         P(M3+3)=P(M3+3)+CP(J3+3)
563    CONTINUE
564   CONTINUE
       M1=M2+1
565   CONTINUE
        WRITE(6,40)
 40     FORMAT(/1X,'ALL DIPOLES WITHIN THE MOSAIC REGIONS'///
     *4X,'DIPOLE',3X,'PARM.',3X,'REGION',5X,'LAT',8X,
     *'LON',5X,'PARAMETER'/6X,'NO.',5X,'NO.',5X,'NO.',
     *28X,'VALUES'//)
C
C  PRINT OUT VALUES FOR ALL DIPOLES WITHIN THE MOSAIC REGIONS
C
      DO 566 J=1,ND
            CALL REGION(J,JOPT,IR)
            IF(JOPT.EQ.1) GO TO 567
            IR=(IR-1)/3+1
            L=(J-1)*3
            LPLUS1=L+1
            WRITE(6,60) J,LPLUS1,IR,ALAT(J),ALON(J),P(L+1)
            LPLUS2=L+2
            WRITE(6,60) J,LPLUS2,IR,ALAT(J),ALON(J),P(L+2)
            LPLUS3=L+3
            WRITE(6,60) J,LPLUS3,IR,ALAT(J),ALON(J),P(L+3)
            GO TO 566
567   CONTINUE
            WRITE(6,60) J,J,IR,ALAT(J),ALON(J),P(J)
 60   FORMAT(3I8,3(5X,F6.2))
566   CONTINUE
771         FORMAT(I5,10F12.5)
C  INITIALIZE VARIABLES TO PERFORM MODEL EVALUATION AGAINST DATA
      A=0.
      B=0.
      NA=0
      NB=0
      LAST=0
      NN=0
      INIT=0
      DO 12 I=1,5
      Q(I)=0.
      SWT(I)=0.
      SMEAN(I)=0.
 12   SIG(I)=0.
C
C  COMPARE DATA WITH SYNTHETIC FIELD COMPUTED FROM PARAMETER SOLUTION
C
        WRITE(6,90)
 90     FORMAT(/1X,'COMPARE DATA WITH COMPUTED VALUES FROM MODEL'//)
      WRITE (6,80)
 80   FORMAT ('0',16X,'RADIAL',13X,'SOUTH',14X,'EAST',12X,'TOTAL FIELD'/
     *)
 38   CALL DATA (INIT,NPTS,LAST)
      DO 800 I=1,NPTS
      X(1)=RLAT(I)
      X(2)=RLON(I)
      X(3)=ELEV(I)
      NN=NN+1
      CALL FUN (JOPT,JCNSTR)
      WRITE (6,89) KK,BR(I),FR,BT(I),FT,BP(I),FP,DF(I),YC
      A=A+ABS(DF(I)-YC)
      B=B+ABS(BR(I)-FR)+ABS(BT(I)-FT)+ABS(BP(I)-FP)
      NA=NA+1
      NB=NB+3
 89   FORMAT (I5,4(5X,2F7.2)/)
      Q(1)=Q(1)+(DF(I)-YC)*(DF(I)-YC)*WTDF
      Q(2)=Q(2)+(BR(I)-FR)*(BR(I)-FR)*WTBR
      Q(3)=Q(3)+(BT(I)-FT)*(BT(I)-FT)*WTBT
      Q(4)=Q(4)+(BP(I)-FP)*(BP(I)-FP)*WTBP
      SMEAN(1)=SMEAN(1)+(DF(I)-YC)
      SMEAN(2)=SMEAN(2)+(BR(I)-FR)
      SMEAN(3)=SMEAN(3)+(BT(I)-FT)
      SMEAN(4)=SMEAN(4)+(BP(I)-FP)
```

```
830 CONTINUE
    IF (LAST.EQ.0) GO TO 88
    A=A/FLOAT(NA)
    B=B/FLOAT(NB)
    SWT(1)=NA*WTDF
    SWT(2)=NA*WTER
    SWT(3)=NA*WTBT
    SWT(4)=NA*WTBP
    DO 13 I=1,4
    Q(5)=Q(5)+Q(I)
    RMS(I)=SQRT(Q(I)/SWT(I))
    SMEAN(5)=SMEAN(5)+SMEAN(I)
    SMEAN(I)=SMEAN(I)/NA
    SWT(5)=SWT(5)+SWT(I)
 13 SIG(I)=SQRT(RMS(I)**2-SMEAN(I)**2)
    RMS(5)=SQRT(Q(5)/SWT(5))
    SMEAN(5)=SMEAN(5)/(4*NA)
          SIG(5)=SQRT(RMS(5)**2-SMEAN(5)**2)
    WRITE (6,111) A
    WRITE (6,222) B
111 FORMAT ('0',' MEAN DIFFERENCE,SCALAR=',F6.2/)
222 FORMAT ('0',' MEAN DIFFERENCE,VECTOR=',F6.2/)
    WRITE (6,333) (RMS(I),I=1,5)
333 FORMAT ('0',' RMS:',5F6.2/)
    WRITE (6,444) (SMEAN(I),I=1,5)
444 FORMAT ('0',' SMEAN:',5F6.2/)
    WRITE (6,555) (SIG(I),I=1,5)
555 FORMAT ('0',' SIG:',5F6.2/)
    WRITE (6,666) (Q(I),I=1,5)
665   FORMAT('0',' Q:      ',5F10.2/)
    IF (L1.EQ.1) WRITE (6,41)
    IF (L2.EQ.1) WRITE (6,42)
    IF (L3.EQ.1) WRITE (6,43)
    IF (L4.EQ.1) WRITE (6,44)
    IF (JOPT.EQ.1) WRITE (6,45)
    IF (JOPT.EQ.0) WRITE (6,46)
C
    WRITE (6,11) NC
 11 FORMAT ('0',I5,' SOURCES'/)
    WRITE (6,10) NE
 10 FORMAT ('0',I5,' PARAMETERS'/)
C   WRITE (6,23)
 23 FORMAT ('0',' PUNCH PARAMETERS'/)
C   WRITE (6,95) (E(I),I=1,NP)
C   WRITE (7,32) (E(I),I=1,NP)
 95 FORMAT (8F8.2/)
 32 FORMAT (7E11.3)
C
C COMPUTE PARAMETER STANDARD DEVIATION
C
    N=3
    IF (JOPT.EQ.1) N=1
    DO 22 J=1,N
    M=J
    SUM=0.
    DO 68 I=M,NP,N
 68 SUM=SUM+P(I)
    AVG=SUM/FLOAT(ND)
    SUM=0.
    DO 69 I=M,NP,N
 69 SUM=SUM+(P(I)-AVG)**2
    SDD(J)=SQRT(SUM/FLOAT(ND))
 22 CONTINUE
    WRITE (6,64) (SDD(J),J=1,N)
 64 FORMAT ('0',' PARAMETER SD=',3E12.4/)
C
C IF SOLUTION IS FOR SOURCE COMPONENTS, COMPUTE ANGLE IN DEGREES
C  BETWEEN VECTOR SOURCE DIRECTIONS AND MAIN FIELD DIRECTION
C
    IF (JOPT.EQ.1) GO TO 67
    WRITE (6,63)
 63 FORMAT ('0',' ANGLE BETWEEN MAGN VECTOR AND MAIN FIELD'/)
          WRITE(6,110)
110   FORMAT(/1X,'DIPOLE LAT. LON.',9X,'P1',6X,'P2',6X,'P3',6X,
   *'P',7X,'FINC  TINC',5X,'FDEC  TDEC',7X,'ANG PHI',5X,
   *'SIGPHI',5X,'SIGMAG'/)
    DO 65 I=1,ND
    II=I
    CALL ANGL (ANG,II)
 65 CONTINUE
 67 CONTINUE
    IF(JCORPR.EQ.1)CALL CORLPR(D,DC,NPCNTR,1)
 8        CONTINUE
```

```
      RETURN
C
400   WRITE(6,50)
50    FORMAT('0',T10,'TOO MUCH DATA REJECTED*******FIT ABORTED')
41    FORMAT ('0',' INPUT RADIAL COMPONENT')
42    FORMAT ('0',' INPUT SOUTH  COMPONENT')
43    FORMAT ('0',' INPUT EAST   COMPONENT')
44    FORMAT ('0',' INPUT ANOM IN TF')
45    FORMAT ('0',' INVERT TO SOURCE MAGNITUDES ONLY')
46    FORMAT ('0',' INVERT TO SOURCE COMPONENTS')
      STOP
      END
      SUBROUTINE TSINV(LL,MM,A,B)
C
C  INVERSION ROUTINE FOR SYMMETRIC MATRIX STORED ROW-WISE
C FOR THE UPPER SYMMETRIC PORTION
        DOUBLE PRECISION DPIV,DSUM,A2,B(1),A(1)
      IDIGL=0
      LTROW=1
      IF(LL.LT.1)GO TO 900
      LL1=LL-1
      K1=0
      LM=MM-LL
      IND=-LM
      DO 90 K=1,LL
      IND=IND+LM
      KPIV=IND+1
      LEND=K-1
      TOL=A(KPIV)
      DO 80 I=K,LL
      IND=IND+1
      DSUM=0.D0
      IF(LEND)30,30,10
10    LANF=K
      LIND=I-K
      DO 20 L=1,LEND
      DSUM=DSUM+A(LANF)*A(LANF+LIND)
      LANF=LANF+MM-L
20    CONTINUE
30    DSUM=A(IND)-DSUM
      IF(I.NE.K)GO TO 70
      IF(DSUM)900,900,40
40    CONTINUE
      IDIG=ALOG10(TOL/SNGL(DSUM))-.5
      IF(IDIG.LE.IDIGL)GO TO 60
      IDIGL=IDIG
      LTROW=I
60    DPIV=DSQRT(DSUM)
      A1=(1.D0/DPIV)
      A2=(1.D0-DBLE(A1)*DPIV)/DPIV
      A(IND)=DPIV
      B(K)=DPIV
      GO TO 80
70    A(IND)=A2*DSUM+DBLE(A1)*DSUM
80    CONTINUE
90    CONTINUE
      DO 152 K=1,LL
      DPIV=A(KPIV)
      A1=(1.D0/DPIV)
      A2=(1.D0-DBLE(A1)*DPIV)/DPIV
      A(KPIV)=A2+DBLE(A1)
      B(LL-K+1)=A(KPIV)
      LEND=K-1
      IF(LEND)130,130,110
110   DO 120 L=1,LEND
      IND=KPIV+L
      A(IND)=-(A2*A(IND)+DBLE(A1)*A(IND))
120   CONTINUE
130   IF(K.EQ.LL)GO TO 152
      IND=KPIV
      KPIV=KPIV-LM-1-K
      LANF=IND
      DO 151 I=K,LL1
      LANF=LANF-LM-I
      DSUM=A(LANF)
      A(LANF)=A2*DSUM+DBLE(A1)*DSUM
      IF(LEND)151,151,140
140   DO 150 L=1,LEND
      LIND=LANF+L
      A(LIND)=A(LIND)+DSUM*A(IND+L)
150   CONTINUE
151   CONTINUE
152   CONTINUE
```

```
      DO 180 K=1,LL
      LIND=KPIV-1
      LANP=KPIV
      DO 170 I=K,LL
      DSUM=0.D0
      DO 160 L=KPIV,IND
      LIND=LIND+1
      DSUM=DSUM+A(L)*A(LIND)
  160 CONTINUE
      A(KPIV)=DSUM
      LIND=LIND+LM
      KPIV=KPIV+1
  170 CONTINUE
C     B(K)=0.D0
      KPIV=KPIV+LM
      IND=IND+MM-K
  180 CONTINUE
          WRITE(6,921) IDIGL,LTROW
  921  FORMAT(//2X,'****** TSINV ******',2X,2I7//)
      RETURN
  930 IDIGL=-1
      LTROW=I
      WRITE(6,920) LTROW
  920 FORMAT(5X,'* * * *      INVERSION FAILED AT ROW',I6)
      STOP 13
      RETURN
      END
      SUBROUTINE FUN (JOPT,JCNSTR)
C   COMPUTES THE PARTIAL DERIVATIVES OF THE OBSERVATIONS WRT ALL
C   DIPOLES IN ALL MOSAIC REGIONS AND THE FIELD VALUES DUE TO ALL
C           DIPOLES REPRESENTED BY THE PARAMETER VECTOR P
       DIMENSION SS(226),CC(226),CS(226),CTH(226),STH(226)
        DIMENSION PCOV(3,3), A(3)
       COMMON/DIPOLE/ ALAT(226),ALON(226)
       COMMON/CP/ CP(680)
       COMMON/BLOKS/ NPCNTR,NDCNTR,IELNUM(1920),NUMEL(1920)
       COMMON/SHR/D(2,60,32)
       COMMON/BHC/P(680),DFDP(680),DFDP1(680),DFDP2(680),DFDP3(680),
     * DFDP4(680),X(3),FR,FT,FP,YC,NP,ND
       REAL*8 DFDP,DFDP1,DFDP2,DFDP3,DFDP4,DNORMX
     *   ,B,BTB,APM,DE,F1,F2,F3,HF2,HF,APSIGM,APSIGI,APSIGD,
     *    SS,CC,CS
       DATA ARC,R/.0174533,6371.2/
       DATA ITOT,JTOT,I1,I2,J1,J2,DIST/32,60,07,21,33,47,100./
           DIMENSION APM(226),APSIGM(226),APSIGI(226),APSIGD(226),B(3,3),
     *                 BTB(3,3)
           COMMON/CHAT/DNORMX(1)
           COMMON/NDIM/NDIM,NJ1,NJ2
           DATA APM/226*10./
           DATA APSIGM/226*1000./
           DATA APSIGI/226*.873/
           DATA APSIGD/226*.873/
           LOC(I,J,NDIM)=(J-1)*NDIM -(J**2-J)/2 + I
        ONE=X(1)
C   DATA STATEMENT SETS VALUES FOR DIPOLE SUB-GRID WHICH ENCOMPASSES
C        ALL MOSAIC REGIONS
C    I1      LOWER LATITUDE GRID NUMBER
C   I2       UPPER LATITUDE GRID NUMBER
C   J1    WESTERN MOST LONGITUDE GRID NUMBER
C   J2     EASTERN MOST LONGITUDE GRID NUMBER
C   DIST     DIPOLE SPACING IN KILOMETERS
        TWO=X(2)
        THREE=X(3)
        THREE = THREE + 6371.2
        CALL FLD (ONE,TWO,THREE)
        DC=ONE
        BC=TWO
        EC=THREE
        T=R+X(3)
        TCR=(90.-X(1))*ARC
        CTC=COS(TCR)
        STC=SIN(TCR)
        FR=0.
        FT=0.
        FP=0.
        YC=0.
        DO 57 I=1,ND
        L=(I-1)*3
        CTD=STH(I)
        STD=CTH(I)
        DPH=(X(2)-ALON(I))*ARC
        CDP=COS(DPH)
        SDP=SIN(DPH)
```

```
      DD=SS(I)
      BD=CC(I)
      CD=CS(I)
      A1=CTD*CTC+STD*STC*CDP
      B1=CTC*STD-STC*CTD*CDP
      C1=STC*SDP
      A2=-STC*CTD+CTC*STD*CDP
      B2=-STC*STD-CTC*CTD*CDP
      C2=CTC*SDP
      A3=-STD*SDP
      B3=CTD*SDP
      C3=CDP
      E=R*R+T*T-2.*T*R*A1
      C=SQRT(E)
      C=C*E
      C=VOL/C
      F1=T*A1-R
      F2=-T*B1
      F3=T*C1
      D1=T-R*A1
      D2=-R*A2
      D3=-R*A3
      D1=3.*D1
      D2=3.*D2
      D3=3.*D3
      F1=F1/E
      F2=F2/E
      F3=F3/E
      D11=C*(D1*F1-A1)
      D12=C*(D1*F2+B1)
      D13=C*(D1*F3-C1)
      D21=C*(D2*F1-A2)
      D22=C*(D2*F2+B2)
      D23=C*(D2*F3-C2)
      D31=C*(D3*F1-A3)
      D32=C*(D3*F2+B3)
      D33=C*(D3*F3-C3)
      IF (JOPT.EQ.1) GO TO 30
C
C FOR ESTIMATING SOURCE COMPONENTS
C
      DFDP1(L+1)=D11
      DFDP1(L+2)=D12
      DFDP1(L+3)=D13
      DFDP2(L+1)=D21
      DFDP2(L+2)=D22
      DFDP2(L+3)=D23
      DFDP3(L+1)=D31
      DFDP3(L+2)=D32
      DFDP3(L+3)=D33
      DFDP4(L+1)=D11*DC+D21*BC+D31*EC
      DFDP4(L+2)=D12*DC+D22*BC+D32*EC
      DFDP4(L+3)=D13*DC+D23*BC+D33*EC
      FR=FR+D11*P(L+1)+D12*P(L+2)+D13*P(L+3)
      FT=FT+D21*P(L+1)+D22*P(L+2)+D23*P(L+3)
      FP=FP+D31*P(L+1)+D32*P(L+2)+D33*P(L+3)
      YC=DFDP4(L+1)*P(L+1)+DFDP4(L+2)*P(L+2)+DFDP4(L+3)*P(L+3)+YC
      GO TO 31
   30 CONTINUE
C
C FOR ESTIMATING SOURCE MAGNITUDES
C
      DFDP1(I)=DD*D11+BD*D12+CD*D13
      DFDP2(I)=DD*D21+BD*D22+CD*D23
      DFDP3(I)=DD*D31+BD*D32+CD*D33
      DFDP4(I)=DC*DFDP1(I)+BC*DFDP2(I)+EC*DFDP3(I)
      FR=P(I)*DFDP1(I)+FR
      FT=P(I)*DFDP2(I)+FT
      FP=P(I)*DFDP3(I)+FP
      YC=P(I)*DFDP4(I)+YC
   31 CONTINUE
C
C (FR,FT,FP) IF ANOMALY FIELD VECTOR IN RADIAL,SOUTH,AND EAST
C  DIRECTIONS, RESPECTIVELY
C
C YC IS ANOMALY IN THE TOTAL FIELD
C
   57 CONTINUE
      RETURN
C
      ENTRY FUN2 (JOPT,JCNSTR)
C
         NJ1=J1
```

```
         NJ2=J2
      ONE=0.
      TWO=0.
      THREE=0.
      THREE = THREE + 6371.2
      CALL FLD (ONE,TWO,THREE)
C
C FLD TAKES (ONE,TWO,THREE)=(LATITUDE,LONGITUDE,ELEVATION)
C RETURNS (ONE,TWO,THREE)=(SIN I,COS I*COS D,COS I,SIN D) COMPUTED
C  FROM A FIELD MODEL, WHERE (I,D) ARE (INCLINATION,DECLINATION)
C
C READ SOURCE LOCATIONS FOR FULL 60X32) REGION INTO ARRAY D(2,60,32
C
            DO 111   J = 1,JTOT
       DO 51  I = 1,6
       ISTRT = 1 + 6*(I-1)
       IEND = ISTRT + 5
       IEND = MINO(IEND,ITOT)
       READ(5,2)  (D(1,J,K),D(2,J,K),K=ISTRT,IEND)
  51   CONTINUE
 111   CONTINUE
  3    FORMAT(3F10.5,2I5)
  2    FORMAT(12F6.2)
C
C TREAT SUBSET OF SOURCES WHICH WILL COMPRISE TOTAL OF MOSAIC REGIONS
C
      L=0
      DO 8 I=I1,I2
      DO 8 J=J1,J2
      L=L+1
      ONE=D(1,J,I)
      TWO=D(2,J,I)
      THREE=0.
C
C LAT,LON SOURCE POSITIONS
C
         IF(L.EQ. 111) ONE=ONE + .1
         IF(L.EQ. 111) TWO=TWO + .45
         IF(L.EQ. 112) ONE=ONE - .4
         IF(L.EQ. 112) TWO=TWO + .4
         IF(L.EQ. 127) ONE=ONE - .4
         IF(L.EQ. 127) TWO=TWO + .5
      ALAT(L)=ONE
      ALON(L)=TWO
      TH=ONE*ARC
      CTH(L)=COS(TH)
      STH(L)=SIN(TH)
C
C TO FIX SOURCE VECTOR ORIENTATION IN MAIN FIELD DIRECTION
C
       THREE = THREE + 6371.2
      CALL FLD (ONE,TWO,THREE)
      SS(L)=ONE
      CC(L)=TWO
      CS(L)=THREE
C
    8 CONTINUE
      ND=L
      NP=ND
      IF (JOPT.NE.1) NP=ND*3
      VOL=DIST*DIST*40.
         ISIZE=NP*(NP + 1)/2
C        IF(ISIZE.GT.NDIM) STOP 15
C     ZERO NORMAL MATRIX AND A PRIORI PARAMETER VALUES
         DO 5 J=1,NP
         P(J)=0.
 5     CONTINUE
         DO 7 J=1,NDIM
 7     DNORMX(J)=0.D0
         IF(JCNSTR .EQ.0) RETURN
         IF(JOPT.EQ.0) GO TO 100
C
C IF STATISTICAL A PRIORI CONSTRAINTS ARE TO BE IMPOSED, PROCEED
C
C     SET A PRIORI PARAMETER VALUES AND NORMAL MATRIX
      M1=1
      DO 50 J=1,NDCNTR
      M2=M1+NUMEL(J)-1
      CP(J)=APM(J)
      LC=LOC(J,J,NDCNTR)
      DNORMX(LC)=DNORMX(LC)  + 1.0D0/APSIGD(J)**2
       DO 40 M=M1,M2
        P(IELNUM(M))=APM(J)
```

```
  40      CONTINUE
        M1=M2+1
  50    CONTINUE
C
C
           RETURN
C       SET A PRIORI PARAMETER VALUES AND NORMAL MATRIX
 100    L=-2
        M1=1
           DO 150 I=1,NDCNTR
        M2=M1+NUMEL(J)-1
        F1=0.D0
        F2=0.D0
        F3=0.D0
        DO 110 M=M1,M2
        F1=F1+SS(IELNUM(M))
        F2=F2+CC(IELNUM(M))
        F3=F3+CS(IELNUM(M))
 110    CONTINUE
        F1=F1/NUMEL(J)
        F2=F2/NUMEL(J)
        F3=F3/NUMEL(J)
        J3=3*(J-1)
        DO 120 M=M1,M2
        M3=3*(IELNUM(M)-1)
        P(M3+1)=APM(J)*F1
        P(M3+2)=APM(J)*F2
        P(M3+3)=APM(J)*F3
 120    CONTINUE
        CP(J3+1)=APM(J)*F1
        CP(J3+2)=APM(J)*F2
        CP(J3+3)=APM(J)*F3
        L=J3+1
           HF2=F2*F2 + F3*F3
           HF=DSQRT(HF2)
           B(1,1)=F1/APSIGM(I)
           B(1,2)=F2/APSIGM(I)
           B(1,3)=F3/APSIGM(I)
           B(2,1)=HF/DM/APSIGI(I)
           B(2,2)=-F1*F2/HF/DM/APSIGI(I)
           B(2,3)=-F1*F3/HF/DM/APSIGI(I)
           B(3,1)=0.D0
           B(3,2)=-F3/HF2/DM/APSIGD(I)
           B(3,3)= F2/HF2/DM/APSIGD(I)
           CALL TMULT(B,BTB)
           LC=LOC(L,L,NPCNTR)
           DNORMX(LC  )=BTB(1,1)
           DNORMX(LC+1)=BTB(1,2)
           DNORMX(LC+2)=BTB(1,3)
           LP1=L + 1
           LC=LOC(LP1,LP1,NPCNTR)
           DNORMX(LC)=BTB(2,2)
           DNORMX(LC + 1)=BTB(2,3)
           LP2=L + 2
           LC=LOC(LP2,LP2,NPCNTR)
           DNORMX(LC)=BTB(3,3)
        M1=M2+1
C          WRITE(6,900) B(1,1),B(1,2),B(1,3),BTB(1,1),BTB(1,2),BTB(1,3)
C          WRITE(6,900) B(2,1),B(2,2),B(2,3),BTB(2,1),BTB(2,2),BTB(2,3)
C          WRITE(6,900) B(3,1),B(3,2),B(3,3),BTB(3,1),BTB(3,2),BTB(3,3)
 900       FORMAT(10X,3G14.7,10X,3G14.7)
 150         CONTINUE
             RETURN
C
C  COMPUTE ANGLE BETWEEN DIPOLE AND MAIN FIELD AND THE STANDARD DEVIATIC
        ENTRY ANGL (ANG,II)
C
        LL=0
        I=II
        L=(I-1)*3
        X(1)=ALAT(I)
        X(2)=ALON(I)
        X(3)=0.
         X(3) = X(3) + 6371.2
        CALL FDG (1,0,0,X(1),X(2),X(3),1968.,50,LL,A1,A2,A3,A4)
         PHIC=ATAN2(A2,-A1)
        C2=-A1/A4
        C3=A2/A4
        C1=-A3/A4
        TDEC=PHIC/0.0174533
        TINC=ARSIN(C1)/0.0174533
        ANG=0.
        IF (JOPT.EQ.1)GO TO 9
```

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      P1=P(L+1)
      P2=P(L+2)
      P3=P(L+3)
      RM=SQRT(P1*P1+P2*P2+P3*P3)
      IF (RM.EQ.0.) RETURN
      B1=P1/RM
      B2=P2/RM
      B3=P3/RM
      ANG=ARCOS(B1*C1+B2*C2+B3*C3) /0.0174533
      FINC=ARSIN(B1)/0.0174533
      FDEC=ATAN2(P3,P2)/0.0174533
C   DETERMINE IN WHICH MOSAIC REGION THE DIPOLE IS LOCATED
      CALL REGION(I,JOPT,IP)
      IP3=IP+2
      DO 20 IC=IP,IP3
      DO 20 JC=IP,IP3
      LC=LOC(IC,JC,NPCNTR)
      IF(IC.LE.JC)  IC=LOC(JC,IC,NPCNTR)
 20   PCOV(IC-IP+1,JC-IP+1)=DNORMX(LC)
      COSP=B1*C1+B2*C2+B3*C3
      SINP=SQRT(1.0-COSP*COSP)
      A(1)=(C1-COSP*B1)/(RM*SINP)
      A(2)=(C2-COSP*B2)/(RM*SINP)
      A(3)=(C3-COSP*B3)/(RM*SINP)
      SIGPHI=0.D0
      DO 12 L=1,3
      DO 14 K=1,3
 14       SIGPHI=SIGPHI+A(K)*PCOV(K,L)*A(L)
 12   CONTINUE
      SIGPHI=SQRT(SIGPHI)/(.0174533)
          A(1)=B1
          A(2)=B2
          A(3)=B3
          SIGMAG=0.
          DO 16 L=1,3
          DO 16 K=1,3
 16       SIGMAG=SIGMAG + A(K)*PCOV(K,L)*A(L)
          SIGMAG=SQRT(SIGMAG)
      GO TO 10
 9    CONTINUE
      RM=P(I)
      P1=-RM*C1
      P2=-RM*C2
      P3= RM*C3
      FINC=TINC
      FDEC=TDEC
 10   CONTINUE
      WRITE(6,33)I,ALAT(I),ALON(I),P1,P2,P3,RM,FINC,TINC,
     .  FDEC,TDEC,ANG,SIGPHI,SIGMAG
C     WRITE(7,35)  I,ALAT(I),ALON(I),P1,P2,P3,RM,FINC,TINC,
     .  FDEC,TDEC,ANG
C
C  (P1,P2,P3,)=MAGNETIZATION VECTOR COMPONENTS
C  (ALAT,ALON)=MAGNETIZATION VECTOR POSITIONS
C  (TDEC,TINC)=DECLINATION,INCLINATION OF MAIN FIELD
C  (FDEC,FINC)=DECLINATION,INCLINATION OF MAGNETIZATION VECTOR
C  RM=VECTOR SUM OF MAGN COMPONENTS IF SOLUTION IS FOR VECTOR
C   ORIENTATION, POSITIVE OR NEGATIVE MAGNETIZATION IF SOLUTION
C   IS FOR MAGNITUDE ONLY
C  ANG IS ANGLE BETWEEN MAIN FIELD (POGO0272) AND SOLUTION VECTORS
 33     FORMAT('0',I5,2F6.1,3X,4F8.2,3X,2F6.0,3X,2F6.0,3X,F10.0,
     .F10.2,2X,F10.2/)
 35   FORMAT(I5,2F6.1,4F7.2,2F6.0,2F6.0,F10.0)
      RETURN
      END
C
          SUBROUTINE TMULT(B,BTB)
C     CALCULATES THE MATRIX  BTB= B X BT
          REAL * 8      B(3,3),BTB(3,3)
          DO 20 I=1,3
          DO 10 J=1,3
          BTB(I,J)=0.D0
          DO 5 K=1,3
 5      BTB(I,J)=BTB(I,J)  + B(K,I)*B(K,J)
 10       CONTINUE
 20       CONTINUE
          RETURN
          END
      SUBROUTINE FLD (ONE,TWO,THREE)
      DATA L/1/
      CALL FDG (1,0,0,ONE,TWO,THREE,1968.,50,L,A1,A2,A3,A4)
      ONE=-A3/A4
      TWO=-A1/A4
```

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      THREE=+A2/A4
      L=0
      RETURN
      END
      SUBROUTINE DATA (INIT,NPTS,LAST)
C  SELECT DATA IN PROFILES OVER THE SUB-GRID REGION DEFINED BY
C     I1,I2,J1,J2 IN DATA STATEMENT
      DIMENSION DE(3,60,32),D1(3,60,32),D2(3,60,32),D3(3,60,32)
      DIMENSION LE(3),HT(3)
      COMMON/SHR/D(2,60,32)
      COMMON/REC/RLAT(32),RLON(32),ELEV(32),DF(32),BR(32),BT(32),BP(32)
          COMMON/DATAST/IDAT,IDUM,YC,FA,FT,FP
      REAL*8 STD,DMEAN,FI
      DATA ITOT,JTOT,I1,I2,J1,J2/32,60,06,22,32,48/
      IF (INIT.NE.0) GO TO 50
      INIT=1
      LL=0
      JJ=0
      K=1
      IF (LE(K).EQ.0) K=K+1
      IF (LE(K).EQ.0) K=K+1
      J=J1
   50 CONTINUE
      L=0
      DO 16 I=I1,I2
      L=L+1
      LL=LL+1
      RLAT(L)=D(1,J,I)
      RLON(L)=D(2,J,I)
      ELEV(L)=HT(K)
      BR(L)=-D3(K,J,I)
      BT(L)=-D1(K,J,I)
      BP(L)=D2(K,J,I)
   16 DF(L)=DE(K,J,I)
      JJ=JJ+1
      NPTS=L
      WRITE (6,8) JJ,NPTS,K
          J=J + 1
    8 FORMAT ('0',' PROFILE',I5,',',I5,' POINTS,    TIER',I2/)
      IF (LL.EQ.NTOT) GO TO 20
      IF (J.LE.J2)    GO TO 17
      J=J1
      K=K+1
      IF (LE(K).EQ.0) K=K+1
   17 CONTINUE
      RETURN
   20 CONTINUE
      LAST=1
      WRITE (6,21)
   21 FORMAT ('0', ' END OF DATA SET'/)
      WRITE (6,22) NTOT,JJ
   22 FORMAT ('0',I5,' POINTS FROM',I5,' PROFILES'/)
      RETURN
C
      ENTRY DATA2
C
C
C    NOIS=0  NO NOISE
C    NOIS=1  NOISE
      NOIS=0
C     NOIS=1
      NMBR=3
      K=2
      LE(1)=0
      LE(2)=1
      LE(3)=0
C
C  DATA POINT LOCATION GRID
C
C
C  USE DATA POINT SUB-GRID FOR INPUT
C
C  SIMULATED DATA MAY BE INPUT FROM THREE POSSIBLE ELEVATIONS, HT(I)=350,
C        450, AND 550 KM, DEPENDING ON WHETHER LE(I)=1
C  NTOT=NMBR OF LEVELS USED
C  NTOT=TOTAL NMBR INPUT DATA POINTS
C
      IT=I2-I1+1
      JT=J2-J1+1
      HT(1)=350.
      HT(2)=325.
      HT(3)=550.
      NTOT=0
```

```
      DO 7 I=1,3
      IF (LE(I).EQ.1) NTOT=NTOT+1
    7 CONTINUE
      NTOT=IT*JT*NTOT
C
C READ IN ALL 'DATA' (SIMULATED)
C DE IS ANOMALY IN TOTAL FIELD
C (D1,D2,D3) ARE (RADIAL,SOUTH,EAST) COMPONENTS
C
       DO 136  I = 1,31
       DO 135  J = 1,6
       ISTRT = 1 + 11*(J-1)
       IEND = ISTRT + 10
       IEND = MIN0(IEND,60)
       READ(5,130)  (DE(K,JJ,I),JJ=ISTRT,IEND)
  135  CONTINUE
  136  CONTINUE
       DO 146  I = 1,31
       DO 145  J = 1,6
       ISTRT = 1 + 11*(J-1)
       IEND = ISTRT + 10
       IEND = MIN0(IEND,60)
       READ(5,130)  (D1(K,JJ,I),JJ=ISTRT,IEND)
  145  CONTINUE
  146  CONTINUE
       DO 156  I = 1,31
       DO 155  J = 1,6
       ISTRT = 1 + 11*(J-1)
       IEND = ISTRT + 10
       IEND = MIN0(IEND,60)
       READ(5,130)  (D2(K,JJ,I),JJ=ISTRT,IEND)
  155  CONTINUE
  156  CONTINUE
       DO 166  I = 1,31
       DO 165  J = 1,6
       ISTRT = 1 + 11*(J-1)
       IEND = ISTRT + 10
       IEND = MIN0(IEND,60)
       READ(5,130)  (D3(K,JJ,I),JJ=ISTRT,IEND)
  165  CONTINUE
  166  CONTINUE
  130  FORMAT(11F7.2)
C
      IF (NOIS.EQ.0) GO TO 11
C
C ADD NOISE TO 'DATA'
C
      DMEAN=0.
      STD=6.
      IX=231457
      DO 9 I=1,ITOT
      DO 9 J=1,JTOT
      CALL GNORML (IX,STD,DMEAN,PI)
      D1(K,J,I)=D1(K,J,I)+PI
      CALL GNORML (IX,STD,DMEAN,PI)
      D2(K,J,I)=D2(K,J,I)+PI
      CALL GNORML (IX,STD,DMEAN,PI)
      D3(K,J,I)=D3(K,J,I)+PI
    9 CONTINUE
      STD=1.
      IX=80911
      DO 10 I=1,ITOT
      DO 10 J=1,JTOT
      CALL GNORML (IX,STD,DMEAN,PI)
   10 DE(K,J,I)=DE(K,J,I)+PI
   11 CONTINUE
      RETURN
      END
      SUBROUTINE GNORML (IY,STD,DMEAN,PI)
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 Y
      A=0.D0
      DO 50 I=1,12
      CALL RANDU (IY,IX,Y)
      IY=IX
   50 A=A+Y
      PI=(A-6.D0)*STD+DMEAN
      RETURN
      END
      SUBROUTINE CCRIPR(D,S,NOR,NT)
      REAL*8 D(1),S(1),COVMIN
C      K=PTR IN D  I=ROW PTR  J=COL PTR
C      D ARRAY HOLDS NORMAL EQUATIONS OR COVARIANCE MATRIX
```

```
C
C       S IS PRINTOUT ARRAY
C
          IF(NT.EQ.0) GO TO 320
      DO 300 J=1,NOR
      LC=(J-1)*NOR-(J*J-3*J)/2-1
      DO 300 M=J,NOR
      LC=LC+1
  300 D(LC)=D(LC)/DSQRT(S(M)*S(J))
  320     CONTINUE
C
      K=1
      WRITE(6,720) K
      WRITE(6,730) D(K)
      DO 400 J=2,NOR
      K=J
      DO 350 I=1,J
       S(I)=D(K)
  350  K=K+NOR-I
      WRITE(6,720) J
      WRITE(6,730)  (S(I),I=1,J)
  400 CONTINUE
      RETURN
  720 FORMAT(/'  J =',I5)
  730 FORMAT(' ',13F10.2)
      END
      SUBROUTINE BLKS(NDCNTR,NUMEL,IELNUM)
      DIMENSION NUMEL(1920)  , IELNUM(1920)
          COMMON/NDIM/NDIM,J1,J2
C
C           SUBROUTINE BLKS IS USED TO INPUT THE INFORMATION
C           DEFINING THE DIPOLES COMPRISING THE MOSAIC REGIONS
C           SUBROUTINE BLKS TASK IS TO DETERMINE THE
C           ELEMENT NUMBERS  OF EACH CONSTRAINT BLOCK.
C           CURRENTLY THE SUBROUTINE IS GEARED TO
C           A GRID OF DIPOLES   32 X 60   IS SIZE.
C
C
C           INPUT FOR THIS SUBROUTINE SHOULD BE AS FOLLOWS:
C   ROW AND COLUMN NUMBERS ARE RELATIVE TO THE DIPOLE SUB-GRID
C     REGION DEFINED IN SUBROUTINE FUN
C
C     NUMBER OF MOSAIC REGIONS
C    ROW NUMBER OF FIRST MOSAIC BLOCK , NUMBER OF ENTRIES FOR BLOCK
C     COL NUMBER OF FIRST ENTRY, NUMBER OF COLS IN FIRST ENTRY, ROW NUM
C     COL NUMBER OF SECOND ENTRY , NUMBER OF COLS IN SECOND ENTRY, ROW
C       .
C       .
C       .
C     ROW NUMBER OF SECOND MOSAIC BLOCK , NUMBER OF ENTRIES FOR BLOCK
C     COL NUMBER OF FIRST ENTRY , NUMBER OF COLS IN ENTRY,ROW NUMBER
C     COL NUMBER OF SECOND ENTRY , NUM OF COLS IN ENTRY,ROW NUMBER
C       .
C       .
C       .
C
C
C
      NCL=J2-J1+1
      ITOTAL=0
      DO 10 I=1,1920
        NUMEL(I)=0
        IELNUM(I)=0
   10 CONTINUE
C
C           READ THE NUMBER OF MOSAIC REGIONS
C
      READ(9,50) NDCNTR
C
          WRITE(6,65) NDCNTR
   65  FORMAT(//'**********'//'    NO. OF REGIONS IS ',I5///)
      DO 40 I=1,NDCNTR
        READ(9,50) IROW,NUMROW
          IROW=IROW-1
        DO 30 J=1,NUMROW
          IROW=IROW+1
          READ(9,50) ICOL,NUMCOL,IROW
          NUMEL(I)=NUMEL(I)+NUMCOL
          ISTRT=(IROW-1)*NCL + ICOL-1
          DO 20 K=1,NUMCOL
            IELNUM(ITOTAL+K)=ISTRT+K
          ICK=ICOL-1 +K
```

```
        ITK=ITOTAL + K
        ISK=ISTRT + K
20      CONTINUE
        ITOTAL=ITOTAL+NUMCOL
30    CONTINUE
40  CONTINUE
C
60      FORMAT(10X,6I10)
C
      WRITE(6,15)
15  FORMAT(//10X,'REGION',10X,'NUMBER OF DIPOLES'//)
    DO 45 I1=1,NCCNTR
    WRITE(6,55) I1,NUMEL(I1)
45  CONTINUE
C
    RETURN
50  FORMAT(3I3)
55  FORMAT(5X,I9,6X,I15)
    END
    SUBROUTINE FDG (J,MM,NEXT,DLAT,DLONG,Q,TM,NMX,L,X,Y,Z,F)
C*************************************************************************
C   J.EQ.0      INPUTS LATITUDE & Q=ALTITUDE (KM) RELATIVE TO ELLIPSOID
C               (GEODETIC COORDINATES)
C   J.EQ.0      OUTPUT FIELD COMPONENTS NORTH,EAST,VERTICAL
C               IN GEODETIC COORDINATES
C
C   J.NE.0      LAT.&LONG IN SPHERICAL COORDINATES, Q=GEOCENTRIC RADIUS(KM)
C   J.NE.0      OUTPUT FLD COMPONENTS NORTH,EAST,VERTICAL IN SPHERICAL COOR
C
C   MM.EQ.0     USE DEFAULT VALUES AE=6378.16,FLAT=298.25
C   MM.NE.0     INPUT VALUES FOR AE,FLAT      ON FIRST CALL TO FDG
C
C   NEXT.EQ.0 DO NOT READ INPUT VALUES FOR EXTERNAL FIELD PARAMETERS
C             WHEN L IS GREATER THAN 0
C   NEXT.EQ.0 DO NOT EVALUATE EXTERNAL FIELD FROM MODEL
C   NEXT.NE.0 READ INPUT VALUES FOR EXTERNAL FIELD PARAMETERS WHEN
C             L GREATER 0
C   NEXT.NE.0 EVALUATE EXTERNAL FIELD MODEL
C
C   DLAT        GEODETIC LATITUDE IN DEGREES WHEN J=0
C               GEOCENTRIC LATITUDE IN DEGREES WHEN J=1
C
C   DLONG       LONGITUDE IN DEGREES
C
C   Q           GEODETIC ALTITUDE (KM) WHEN J=0
C               GEOCENTRIC RADIUS (KM) WHEN J=1
C
C   NMAX        MAXIMUM DEGREE AND ORDER OF CONSTANT TERMS OF FIELD MODEL
C   NMAXT       "       "       "     FIRST ORDER TIME    "    "    "
C   NMAXTT      "       "       "     SECOND   "     "    "    "    "
C   NMXTTT      "       "       "     THIRD    "     "    "    "    "
C
C   K.EQ.0      FIELD MODEL COEFFICIENTS SCHMIDT NORMALIZED
C   K.NE.0      FIELD MODEL COEFFICIENTS GAUSS NORMALIZED
C
C   TZERO       EPOCH TIME FOR FIELD MODEL COEFFICIENTS
C
C   ABAR        MEAN RADIUS USED IN FIELD MODEL POTENTIAL EXPANSION
C               (DEFAULT = 6371.2)
C
C   MODEXT.EQ.0 NO EXTERNAL FIELD SOLVED WITH MODEL
C   MODEXT.NE.0 EXTERNAL FIELD SOLVED WITH MODEL
C   L.EQ.0        EVALUATE FIELD
C   L.GT.0        READ IN FIELD MODEL AND EVALUATE FIELD
C   L.LE.0        EVALUATE FIELD AT OLD TIME
C
C*************************************************************************
      EQUIVALENCE (SHMIT(1,1),TG(1,1))
      COMMON /COEFFS/TG(18,18)
      COMMON /FLDCOM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B,
     &ABAR,E1,E2,E3,NEXTP
      DIMENSION G(18,18),GT(18,18),SHMIT(18,18),AID(33)
      DIMENSION GTTT(8,8),GTT(18,18)
      DATA IFRST/0/
      DATA AE,FLAT/6378.16,298.25/
      DATA TLAST/0./
      DATA TABAR/6371.2/
      IF(IFRST) 110,100,110
C                                                                       C
C         EQUATORIAL EARTH RADIUS AND FLATTENING FACTOR                 C
C         USED IN GEODETIC-GEOCENTRIC COORDINATES.                      C
C                                                                       C
C         THE MODEL ITSELF IS INDEPENDENT OF THOSE                      C
```

```
C
C        PARAMETERS                                                          C
C                                                                            C
 100  IF(MM.NE.0)READ(5,101) AE,FLAT
 101  FORMAT(1X,2F6.1)
      WRITE(6,109) AE,FLAT
 109  FORMAT(//5X,'CONSTANTS USED : '/,22X,'EQUATORIAL EARTH RADIUS   ',
     &F8.3/,22X,'EARTH RECIPROCAL FLATTENING   ',F6.1//)
      IFRST=1
      FLAT=1. -1./FLAT
      E1=0.
      E2=0.
      E3=0.
      A2=AE**2
      A4=A2**4
      B2=(AE*FLAT)**2
      A2B2=A2*(1.-FLAT**2)
      A4B4=A4*(1.-FLAT**4)
 110  IF (L) 19,1,2
 1    IF (TM-TLAST) 17,19,17
 2    READ (5,3) NMAX,NMAXT,NMAXTT,NMXTTT,MODEXT,K,TZERO,ABAR,
     &(AID(I),I=1,10)
 3    FORMAT(4I2,2I2,2F6.1,12A4,A2)
      IF (ABAR.EQ.0.) ABAR=TABAR
      READ(5,103)  (AID(I),I=14,33)
 103  FORMAT(20A4)
      L=0
      WRITE (6,104)  (AID(I),I=1,33)
 104  FORMAT  (25X,12A4,A2/5X,20A4//)
      WRITE(6,105) NMAX,NMAXT,NMAXTT,NMXTTT,MODEXT,K,TZERO,ABAR
 105  FORMAT(5X,'FIELD MODEL ORDER (',I2,',',I2,',',I2,',',I2,')'/,
     &5X,'EXTERNAL FIELD SOLVED WITH MODEL ( 0-NO; 1-YES)',I2/,
     &5X,'NORMALIZATION  (K=0-SCHMIDT ; K.NE.0-GAUSS)',I2/,
     &5X,'FIELD MODEL EPOCH   ',F6.1/,
     &5X,'FIELD MODEL MEAN RADIUS ',F6.1//)
      MAXN=0
      TEMP=0.
 5    READ (5,6) N,M,GNM,HNM,GTNM,HTNM,GTTNM,HTTNM
 6    FORMAT  (2I3,6F11.4)
      IF  (N.LE.0)  GOTO7
      MAXN=(MAX0(N,MAXN))
      G(N,M)=GNM
      GT(N,M)=GTNM
      GTT(N,M)=GTTNM
      TEMP=AMAX1(TEMP,ABS(GTNM))
      IF  (M.EQ.1)  GOTO5
      G(M-1,N)=HNM
      GT(M-1,N)=HTNM
      GTT(M-1,N)=HTTNM
      GO TO 5
 7    IF(NMXTTT.EQ.0) GO TO 107
 106  READ(5,6)N,M,GTTTNM,HTTTNM
      IF (N.EQ.0)  GO TO 107
      IF (N.GT.8)  STOP 106
      GTTT(N,M)=GTTTNM
      IF (M.EQ.1)  GO TO 106
      GTTT(M-1,N)=HTTTNM
      GO TO 106
 107  CONTINUE
      IF(MODEXT.NE.0) READ(5,102)  E1,E2,E3
 102  FORMAT(6X,3F9.2)
      WRITE(6,8)
 8    FORMAT(6H0 N   M,6X1HG,10X1HH,9X2HGT,9X2HHT,8X3HGTT,
     &8X3HHTT,7X4HGTTT,7X4HHTTT//)
      DO 12 N=2,MAXN
      DO 12 M=1,N
      MI=M-1
      IF  (M.EQ.1)  GOTO10
      IF(N.GT.NMXTTT) WRITE(6,9)N,M,G(N,M),G(MI,N),
     &GT(N,M),GT(MI,N),GTT(N,M),GTT(MI,N)
      IF(N.LE.NMXTTT) WRITE(6,9)N,M,G(N,M),G(MI,N),
     &GT(N,M),GT(MI,N),GTT(N,M),GTT(MI,N),GTTT(N,M),GTTT(MI,N)
 9    FORMAT(2I3,8F11.4)
      GO TO 12
 10   CONTINUE
      IF(N.GT.NMXTTT) WRITE(6,11)N,M,G(N,M),GT(N,M),
     &GTT(N,M)
      IF(N.LE.NMXTTT) WRITE(6,11)N,M,G(N,M),GT(N,M),
     &GTT(N,M),GTTT(N,M)
 11   FORMAT(2I3,F11.4,11X,F11.4,11X,F11.4,11X,F11.4)
 12   CONTINUE
      IF(MODEXT.NE.0)WRITE(6,108) E1,E2,E3
 108  FORMAT(//5X,8HEXTFLD,  ,3F10.2)
 13   FORMAT (1H1)
```

```
      IF (TEMP.EQ.0.) L=-1
   14 IF (K.NE.0) GOTO17
      SHMIT(1,1)=-1.
      DO 15 N=2,MAXN
      SHMIT(N,1)=SHMIT(N-1,1)*FLOAT(2*N-3)/FLOAT(N-1)
      SHMIT(1,N)=0.
      JJ=2
      DO 15 M=2,N
      SHMIT(N,M)=SHMIT(N,M-1)*SQRT(FLOAT((N-M+1)*JJ)/FLOAT(N+M-2))
      SHMIT(M-1,N)=SHMIT(N,M)
   15 JJ=1
      DO 16 N=2,MAXN
      DO 16 M=1,N
      G(N,M)=G(N,M)*SHMIT(N,M)
      GT(N,M)=GT(N,M)*SHMIT(N,M)
      GTT(N,M)=GTT(N,M)*SHMIT(N,M)
      IF (NMXTTT.GT.0.AND.N.LE.8) GTTT(N,M)=GTTT(N,M)*SHMIT(N,M)
      IF (M.EQ.1) GOTO16
      G(M-1,N)=G(M-1,N)*SHMIT(M-1,N)
      GT(M-1,N)=GT(M-1,N)*SHMIT(M-1,N)
      GTT(M-1,N)=GTT(M-1,N)*SHMIT(M-1,N)
      IF (NMXTTT.GT.0.AND.N.LE.8) GTTT(M-1,N)=GTTT(M-1,N)*SHMIT(M-1,N)
   16 CONTINUE
   17 T=TM-TZERO
      DO 18 N=1,MAXN
      DO 18 M=1,N
      TGX=0.
      THX=0.
      IF (M.EQ.1) GO TO 270
      IF (N.GT.NMXTTT) GO TO 210
      TGX=GTTT(N,M)*T
      THX=GTTT(M-1,N)*T
  210 IF (N.GT.NMAXTT) GO TO 220
      TGX=(TGX + GTT(N,M))*T
      THX= (THX + GTT(M-1,N))*T
  220 IF (N.GT.NMAXT) GO TO 230
      TGX= (TGX + GT(N,M))*T
      THX= (THX+GT(M-1,N))*T
  230 TGX=TGX+G(N,M)
      THX=THX+G(M-1,N)
      TG(N,M)=TGX
      TG(M-1,N)=THX
      GO TO 18
  270 CONTINUE
      IF (N.GT.NMXTTT) GO TO 240
      TGX=GTTT(N,M)*T
  240 IF (N.GT.NMAXTT) GO TO 250
      TGX= (TGX+GTT(N,M))*T
  250 IF (N.GT.NMAXT) GO TO 260
      TGX= (TGX+GT(N,M))*T
  260 TGX= TGX+G(N,M)
      TG(N,M)=TGX
   18 CONTINUE
      TLAST=TM
   19 DLATR=DLAT/57.2957795D0
      SINLA=SIN(DLATR)
      RLONG=DLONG/57.2957795D0
      CPH=COS(RLONG)
      SPH=SIN(RLONG)
      IF (J.EQ.0) GOTO20
C
C         Q IS GEOCENTRIC RADIUS WHEN J=1
C
      R=Q
      CT=SINLA
      GO TO 21
   20 SINLA2=SINLA**2
C
C         Q IS GEODETIC ALTITUDE WHEN J=0
C     ALT=Q
C
      COSLA2=1.-SINLA2
      DEN2=A2-A2B2*SINLA2
      DEN=SQRT(DEN2)
      FAC=(((Q*DEN)+A2)/((Q*DEN)+B2))**2
      CT=SINLA/SQRT(FAC*COSLA2+SINLA2)
      R=SQRT(Q*(Q+2.*DEN)+(A4-A4B4*SINLA2)/DEN2)
   21 ST=SQRT(1.-CT**2)
      NMAX=MIN0(NMX,MAXN)
      NEXTF=NEXT
      CALL MAGF
      Y=BP
      F=B
```

```
      IF (J) 22,23,22
22    X=-BT
      Z=-BR
      RETURN
C     TRANSFORMS FIELD TO GEODETIC DIRECTIONS
23    SIND=SINLA*ST-SQRT(COSLA2)*CT
      COSD=SQRT(1.0-SIND**2)
      X=-BT*COSD-BR*SIND
      Z=BT*SIND-BR*COSD
      RETURN
      END
      SUBROUTINE MAGF
      COMMON /COEFFS/G(18,18)
      COMMON/FLDCOM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B,ABAR,E1,E2,E3,NEXT
      DIMENSION P(18,18),DP(18,18),CONST(18,18),SP(18),CP(18),FN(18),FM(
     118)
      IF (P(1,1).EQ.1.0) GO TO 3
1     P(1,1)=1.
      DP(1,1)=0.
      SP(1)=0.
      CP(1)=1.
      DO 2 N=2,18
      FN(N)=N
      DO 2 M=1,N
      FM(M)=M-1
2     CONST(N,M)=FLOAT((N-2)**2-(M-1)**2)/FLOAT((2*N-3)*(2*N-5))
3     SP(2)=SPH
      CP(2)=CPH
      DO 4 M=3,NMAX
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
4     CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
      AOR=ABAR/R
      AR=AOR**2
      BT=0.
      BP=0.
      BR=0.
      DO 8 N=2,NMAX
      AR=AOR*AR
      DO 8 M=1,N
      IF (N-M) 6,5,6
5     P(N,N)=ST*P(N-1,N-1)
      DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)
      GO TO 7
6     P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)
C
C          NOTE : CONST(2,1)=0
C
      DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)
7     PAR=P(N,M)*AR
      IF (M.EQ.1) GO TO 9
      TEMP=G(N,M)*CP(M)+G(M-1,N)*SP(M)
      BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR
      GO TO 10
9     TEMP=G(N,M)*CP(M)
10    BT=BT+TEMP*DP(N,M)*AR
8     BR=BR-TEMP*FN(N)*PAR
      BP=BP/ST
      IF (NEXT.GT.0) CALL EXTFLD
      B=SQRT(BT*BT+BP*BP+BR*BR)
      RETURN
      END
       SUBROUTINE REGION(I,JOPT,IP)
       COMMON/BLOKS/NPCNTR,NDCNTR,IELNUM(1920),NUMEL(1920)
        M1=1
       DO 165 J=1,NDCNTR
       M2=M1+NUMEL(J)-1
        JREG=J
       DO 161 M=M1,M2
       IF(IELNUM(M).EQ.I) GO TO 170
161    CONTINUE
       M1=M2+1
165       CONTINUE
       STOP 199
170     CONTINUE
       IP=JREG
       IF(JOPT.EQ.0) IP=3*(JREG-1)+1
       RETURN
       END
      SUBROUTINE EXTFLD
      COMMON/FLDCOM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B,ABAR,E1,E2,E3
      T1=E2*CPH+E3*SPH
      T2=E1*ST-T1*CT
      T1=E1*CT+T1*ST
```

```
      BR=BR-T1
      BP=BP+E2*SPH-E3*CPH
      BT=BT+T2
      RETURN
      END
// EXEC OLINKGOH,REGION.GO=1000K
//GO.FT05F001 DD DSN=F9#MG.GMCOEF(POGO0272),DISP=SHR,LABEL=(,,,IN)
//          DD DSN=YCDMM.INVERT.AREA(LOC60X32),DISP=SHR,LABEL=(,,,IN)
//    DD DSN=YCDMM.INVERT.AREA(DELTAT),DISP=SHR,LABEL=(,,,IN)
//GO.FT09F001 DD DSN=YCCAB.CONTR.INPUT.KTY03.DATA,DISP=SHR
//GO.FT10F001 DD DSN=YIMAN.KTY03.JOPTL4.DATA,DISP=SHR,LABEL=(,,,OUT)
// EXEC NOTIFYTS
```

APPENDIX B. FLAT EARTH PRISMATIC MODEL

The flat earth software employs the prismatic model of Plouff (Geophysics, Vol. 41, pp. 727-739, 1976) and the linear least squares algorithm described in Appendix A.1 to estimate the magnetization of the prism blocks. The program will operate in two modes:

a) adjust source prism magnetization vector with the direction forced to lie in the main field direction.

b) adjust both the magnitude and direction of the source prism magnetization vector.

Data input to the software is any combination of ΔB_r , ΔB_θ , ΔB_ϕ or ΔB . The local coordinate system utilized is such that $\hat{x}$ is toward the east, $\hat{y}$ is north and $\hat{z}$ is down.

The anomaly data input is accomplished in Subroutine DATA via unit 14 in the same manner identified in Appendix A.3 for the Mosaic Dipole Program. The data sub-region is controlled by the variables I1, I2, J1 and J2 defined in Subroutine DATA. The order of input is ΔB , ΔX , ΔY , ΔZ where ΔX is the anomaly in the north direction, ΔY is the east direction and ΔZ downward in the conventional magnetics notation.

The input defining the prism corner points is accomplished in Subroutine BLOCKS via unit 12. Information is provided in the following order:

a) Number of prisms [format (I5)]

b) Number of corners for prism I [format (I5)]
{lat, long, flat earth X and Y position for each corner point [format (2F6.1, 2F10.2)]

c) Same as b) for prism II

⋮

z) Same as b) for last prism.

The following variables are set in the main program:

ND		the number of prisms to be used.
ZF		the height of the grid of anomaly data to be used in kilometers (note, negative upward).
Z1,Z2		the depths of the prism bodies in kilometers.
JOPT	= 0	estimate source components P_x , P_y , P_z
	1	estimate source magnitude only, with direction along main field.
L1	= 0	do not process ΔB_r data
	1	process ΔB_r data
L2	= 0	do not process ΔB_θ data
	1	process ΔB_θ data
L3	= 0	do not process ΔB_ϕ data
	1	process ΔB_ϕ data
L4	= 0	do not process ΔB data
	1	process ΔB data

APPENDIX B.1 SOURCE LISTING

```
//YCDMM1 JOB (P8002,377,2),FLAT.EARTH,TIME=(01,00),NOTIFY=YCDMA,CLASS=A
/*JOBPARM QUEUE=FETCH
// EXEC OFORTH,PARM=XREF
//SYSIN DD *
      DIMENSION Q(5),SMEAN(5),SIG(5),RMS(5),SDD(3)
      DIMENSION D(196),DW(14),DP(14),DC(14),DCC(14)
      COMMON/DAT/DF(60,31),BT(60,31),BP(60,31),BR(60,31)
      COMMON/BLC/P(14),DFDP(14,4),XF,YF,ZF,FR,FT,FP,YC,NP,ND,Z1,Z2
      COMMON/DMAT/D
      COMMON/NDIM/NDIM
          COMMON/POS/NPRISP,XLAT(4),YLON(4)
      REAL*8 D,DFDP1,DFDP2,DFDP3,DFDP4,DFDP,DW,DP,SUMD,DC,DCC
      DATA I1,I2,J1,J2/06,22,32,48/
      DATA JCORPR/1/,L1,L2,L3,L4,JOPT/1,1,1,0,1/
      DATA DEL,XSW,YSW/.52434,14.79400,2.51220/
      LOC(I,J,NDIM)=(J-1)*NDIM-(J**2-J)/2+I
C
C     ND IS THE NUMBER OF PRISMS TO BE ESTIMATED
C
      ND=3
      NP=ND
C
C     CENTER COORDINATES OF PRISMS
C
          XLAT(1)=42.
          YLON(1)=90.
          XLAT(2)=35.
          YLON(2)=73.
          XLAT(3)=37.
          YLON(3)=85.
      IF(JOPT.EQ.0) NP=3*NP
        NPRISP=NP
      NDIM=(NP*(NP+1))/2
      DO 1 J=1,NDIM
    1 D(J)=0.D0
      FACTOR=7.5*25.4
            ONE=0.
          TWO=0.
            THREE=0.
          THREE=THREE+6371.2
          CALL FLD(ONE,TWO,THREE)
      CALL BLOCKS
      CALL DATA
      CALL ANGL
C
C      JCORPR=0 NO PRINT FOR CORRELATION MATRIX
C      JCORPR=1 PRINT CORRELATION MATRIX
C
C      JOPT=0 TO ESTIMATE SOURCE COMPONENTS
C      JOPT=1 TO ESTIMATE SOURCE MAGNITUDES ONLY
C
C       L1=1 TO INPUT RADIAL FIELD COMPONENT
C       L2=1 TO INPUT SOUTH FIELD COMPONENT
C       L3=1 TO INPUT EAST FIELD COMPONENT
C       L4=1 TO INPUT ANOMALY IN THE TOTAL FIELD
C       FUN RETURNS CORRESPONDING COMPUTED QUANTITIES
C
C
       A=0.
       B=0.
       NA=0
       NB=0
       LAST=0
       NN=0
       INIT=0
       DO 14 I=1,5
       Q(I)=0.
       SMEAN(I)=0.
   14  SIG(I)=0.
       NN=0
       MM=0
C
C      ZERO RIGHT HAND SIDE
C
       DO 2 J=1,NP
       DW(J)=0.D0
       P(J)=0.
    2  CONTINUE
C
```

```
C     DATA HEIGHT
      ZF=-325.
C     DEPTH OF PRISMS
      Z1=0.
      Z2=40.
      DO 20 J=J1,J2
      DO 20 I=I1,I2
      XF=((J-1)*DEL+XSW-34.61)*FACTOR
      IF (DF(J,I).EQ.999.) GO TO 20
      YF=((I-1)*DEL+YSW-9.52)*FACTOR
      CALL FUN(JOPT)
      A=A+ABS(DF(J,I)-YC)
      B=B+ABS(BR(J,I)-FR)+ABS(BT(J,I)-FT)+ABS(BP(J,I)-FP)
      NA=NA+1
      NB=NB+3
      Q(1)=Q(1)+(DF(J,I)-YC)*(DF(J,I)-YC)
      Q(2)=Q(2)+(BR(J,I)-FR)*(BR(J,I)-FR)
      Q(3)=Q(3)+(BT(J,I)-FT)*(BT(J,I)-FT)
      Q(4)=Q(4)+(BP(J,I)-FP)*(BP(J,I)-FP)
      SMEAN(1)=SMEAN(1)+(DF(J,I)-YC)
      SMEAN(2)=SMEAN(2)+(BR(J,I)-FR)
      SMEAN(3)=SMEAN(3)+(BT(J,I)-FT)
      SMEAN(4)=SMEAN(4)+(BP(J,I)-FP)
      MM=MM+1
C     FORM RESIDUALS (OBSERVED-COMPUTED FIELD) DY FOR VARIOUS INPUT
      DO 79 L=1,4
      GO TO (71,72,73,77),L
   71 CONTINUE
      IF (L1.EQ.0) GO TO 79
      NN=NN+1
      DY=(BR(J,I)-FR)
      GO TO 70
   72 CONTINUE
      IF (L2.EQ.0) GO TO 79
      NN=NN+1
      DY=(BT(J,I)-FT)
      GO TO 70
   73 CONTINUE
      IF(L3.EQ.0) GO TO 79
      NN=NN+1
      DY=(BP(J,I)-FP)
      GO TO 70
   77 CONTINUE
      IF (L4.EQ.0) GO TO 79
      NN=NN+1
      DY=(DF(J,I)-YC)
   70 CONTINUE
C     FORM DW AND D MATRICES
      DO 5 JJ=1,NP
      DW(JJ)=DW(JJ)+DFDP(JJ,L)*DY
      LC=LOC(JJ,JJ,NE) - 1
      DO 5 M=JJ,NP
      LC=LC + 1
      D(LC)=D(LC) + DFDP(JJ,L)*DFDP(M,L)
    5 CONTINUE
   79 CONTINUE
      WRITE (6,7) MM,NN,I,J,XF,YF,FR,FT,FP,BR(J,I),BT(J,I),
     *            BP(J,I),DF(J,I)
    7 FORMAT (4I5,4F10.2,F10.1,5X,4F10.2/)
   20 CONTINUE
      IF (NN.LT.NP) GO TO 400
      A=A/FLOAT(NA)
      B=B/FLOAT(NB)
      DO 15 I=1,4
      Q(5)=Q(5)+Q(I)
      RMS(I)=SQRT(Q(I)/NA)
      SMEAN(5)=SMEAN(5)+SMEAN(I)
      SMEAN(I)=SMEAN(I)/NA
   15 SIG(I)=SQRT(RMS(I)**2-SMEAN(I)**2)
      RMS(5)=SQRT(Q(5)/(4*NA))
      SMEAN(5)=SMEAN(5)/(4*NA)
      SIG(5)=SQRT(RMS(5)**2-SMEAN(5)**2)
      WRITE(6,111) A
      WRITE(6,222) B
      WRITE (6,333) (RMS(I),I=1,5)
      WRITE (6,444) (SMEAN(I),I=1,5)
```

```
      WRITE (6,555) (SIG(I),I=1,5)
      WRITE (6,566) (Q(I),I=1,5)
      IF (L1.EQ.1) WRITE (6,41)
      IF (L2.EQ.1) WRITE (6,42)
      IF (L3.EQ.1) WRITE (6,43)
      IF (L4.EQ.1) WRITE (6,44)
      IF (JOPT.EQ.1) WRITE (6,45)
      IF (JOPT.EQ.0) WRITE (6,46)
C
      WRITE (6,11) ND
      WRITE (6,10) NP
      WRITE (6,23)
      WRITE (6,95) (P(I),I=1,NP)
C
C     COMPUTE CHECK SUM COLUMN AND INVERT D MATRIX
C
      DO 6 L=1,NP
      SUMD=0.D0
      DO 4 M=1,NP
      LC=LOC(L,M,NP)
      IF (L.LE.M) LC=LOC(M,L,NP)
    4 SUMD=SUMD + D(LC)
    6 DC(L)=SUMD
      CALL TSINV(NP,NP,D,DPDP)
C
C    FORM PARAMETER CORRECTION VECTOR DP
C
      DO 530 J=1,NP
      DP(J)=0.
      DCC(J)=0.
      DO 530 K=1,NP
       LC= LOC(J,K,NP)
       IF(J.LE.K) LC=LOC(K,J,NP)
      DP(J)=DP(J)+D(LC)*DW(K)
      DCC(J)=DCC(J)+D(LC)*DC(K)
  530 CONTINUE
      WRITE (6,58)
   58 FORMAT(' ',9X,'PO',20X,
     *'P ',20X,'DP',18X,'CHECK',18X,'VAR',20X,'RATIO'//)
      DO 540 J=1,NP
      PO=P(J)
      P(J)=P(J)+DP(J)
      LC=LOC(J,J,NP)
      VAR=DSQRT(D(LC))
      DC(J)=D(LC)
      RATIO=VAR/P(J)
      WRITE(6,53) PO,P(J),DP(J),DCC(J),VAR,RATIO
   53 FORMAT (' ',6D20.8)
  540 CONTINUE
      A=0.
      B=0.
      NA=0
      NB=0
      LAST=0
      NN=0
      INIT=0
      DO 12 I=1,5
      Q(I)=0.
      SMEAN(I)=0.
   12 SIG(I)=0.
C
C COMPARE DATA WITH SYNTHETIC FIELD COMPUTED FROM PARAMETER SOLUTION
C
      WRITE(6,80)
   80 FORMAT ('0',16X,'RADIAL',13X,'SOUTH',14X,'EAST',12X,
     *'TOTAL FIELD')
      DO 800 J=J1,J2
      DO 800 I=I1,I2
      XP=((J-1)*DEL+XSW-34.61)*FACTOR
      IF (DF(J,I).EQ.999.) GO TO 800
      YP=((I-1)*DEL+YSW-9.52)*FACTOR
      NN=NN+1
      CALL FUN(JOPT)
      WRITE(6,89) NN,I,J,BR(J,I),FR,BT(J,I),FT,BP(J,I),FP,DF(J,I),YC
      A=A+ABS(DF(J,I)-YC)
      B=B+ABS(BR(J,I)-FR)+ABS(BT(J,I)-FT)+ABS(BP(J,I)-FP)
      NA=NA+1
      NB=NB+3
   89 FORMAT (1X,3I3,4(5X,2F7.2)/)
      Q(1)=Q(1)+(DF(J,I)-YC)*(DF(J,I)-YC)
      Q(2)=Q(2)+(BR(J,I)-FR)*(BR(J,I)-FR)
      Q(3)=Q(3)+(BT(J,I)-FT)*(BT(J,I)-FT)
      Q(4)=Q(4)+(BP(J,I)-FP)*(BP(J,I)-FP)
```

```
      SMEAN (1) =SMEAN (1) + (DF (J,I) -YC)
      SMEAN (2) =SMEAN (2) + (BR (J,I) -FR)
      SMEAN (3) =SMEAN (3) + (BT (J,I) -FT)
      SMEAN (4) =SMEAN (4) + (BP (J,I) -FP)
  800 CONTINUE
      A=A/FLOAT(NA)
      B=B/FLOAT(NB)
      DO 13 I=1,4
      Q(5) =Q(5) +Q(I)
      RMS(I)=SQRT(Q(I)/NA)
      SMEAN(5) =SMEAN(5) +SMEAN(I)
      SMEAN(I) =SMEAN(I)/NA
   13 SIG(I) =SQRT(RMS(I) **2-SMEAN(I) **2)
      RMS(5) =SQRT(Q(5)/(4*NA))
      SMEAN(5) =SMEAN(5)/(4*NA)
      SIG(5) =SQRT(RMS(5) **2-SMEAN(5) **2)
      WRITE(6,111)  A
      WRITE(6,222)  B
  111 FORMAT  ('0',' MEAN DIFFERENCE ,SCALAR=',F6.2/)
  222 FORMAT  ('0',' MEAN DIFFERENCE ,VECTOR=',F6.2/)
      WRITE  (6,333) (RMS(I) ,I=1,5)
  333 FORMAT  ('0',' RMS:',5F6.2/)
      WRITE  (6,444) (SMEAN(I) ,I=1,5)
  444 FORMAT  ('0',' SMEAN:',5F6.2/)
      WRITE  (6,555) (SIG(I) ,I=1,5)
  555 FORMAT  ('0',' SIG:',5F6.2/)
      WRITE  (6,666)  (Q(I) ,I=1,5)
  666 FORMAT('0',' Q:     ',5F10.2/)
      IF  (L1.EQ.1)  WRITE  (6,41)
      IF  (L2.EQ.1)  WRITE  (6,42)
      IF  (L3.EQ.1)  WRITE  (6,43)
      IF  (L4.EQ.1)  WRITE  (6,44)
      IF  (JOPT.EQ.1) WRITE  (6,45)
      IF  (JOPT.EQ.0) WRITE  (6,46)
C
      WRITE (6,11) ND
   11 FORMAT ('0',I5,' SOURCES'/)
      WRITE (6,10) NE
   10 FORMAT ('0',I5,' PARAMETERS'/)
      WRITE (6,23)
   23 FORMAT ('0',' PRINT PARAMETERS'/)
      WRITE (6,95)  (P(I),I=1,NP)
   95 FORMAT (8F8.2/)
   32 FORMAT (7F11.3)
C
C     IF SOLUTION IS FOR SOURCE COMPONENTS, COMPUTE ANGLE IN
C     DEGREES  BETWEEN VECTOR SOURCE DIRECTIONS AND MAIN FIELD
C     DIRECTION
C
      IF  (JOPT.EQ.1) GO TO 67
      WRITE  (6,63)
   63 FORMAT  ('0',' ANGLE BETWEEN MAGN VECTOR AND MAIN FIELD'/)
      DO 65 J=1,ND
        I=(J-1)*3 + 1
      CALL MAGVEC(J,I,P(I+1),P(I),P(I+2),PHI,PI,PD,SIGPHI,SIGMAG)
C    NORTH
        PX=P(I+1)
C    EAST
        PY=P(I)
C    DOWN
        PZ=P(I+2)
        RM=SQRT(PX*PX+PY*PY+PZ*PZ)
      WRITE(6,64) I,PX,PY,PZ,RM,PHI,PI,PD,SIGPHI,SIGMAG
   64 FORMAT(1X,I3,2X,9(F7.2,3X))
   65 CONTINUE
   67 CONTINUE
      IF  (JCORPR.EQ.1)  CALL  CORLPR (D,DC,NP,1)
  900  CONTINUE
      RETURN
C
  420 WRITE(6,50)
   50 FORMAT('0',T10,'TOO MUCH DATA REJECTED******FIT ABORTED')
   41 FORMAT  ('0',' INPUT RADIAL COMPONENT')
   42 FORMAT  ('0',' INPUT SOUTH COMPONENT')
   43 FORMAT  ('0',' INPUT EAST COMPONENT')
   44 FORMAT  ('0',' INPUT ANOM IN TF')
   45 FORMAT  ('0',' INVERT TO SOURCE MAGNITUDES ONLY')
   46 FORMAT  ('0',' INVERT TO SOURCE COMPONENTS')
      STOP
      END
      SUBROUTINE BLOCKS
      COMMON/BLK/NMBE(5),XX(5,50),YY(5,50),NPSM
C     GIVES COORDINATES OF PRISMATIC BLOCKS IN KM
```

```
C       RELATIVE TO CENTER POINT AT 37N,85W
    5   FORMAT (2I5)
        READ (12,1) NPSM
    1   FORMAT (I5)
        DO 2 I=1,NPSM
        READ (12,5) M,N
        M=M-1
        NMBR(I)=M
        DO 3 J=1,M
    3   READ (12,4) ALAT,ALON,XX(I,J),YY(I,J)
    4   FORMAT (2F6.1,2F10.2)
        READ(12,4) CLAT,CLON,XXX,YYY
    2   CONTINUE
        DO 6 I=1,NPSM
        M=NMBR(I)
        WRITE (6,5) I,M
        DO 7 J=1,M
        XX(I,J)= (XX(I,J)-34.61)*7.5*25.4
        YY(I,J)=(YY(I,J)-9.52)*7.5*25.4
        WRITE (6,8)XX(I,J),YY(I,J)
    8   FORMAT (2F10.0)
    7   CONTINUE
    6   CONTINUE
        RETURN
        END
        SUBROUTINE FLD (ONE,TWO,THREE)
        DATA L/1/
        CALL FDG (1,0,0,ONE,TWO,THREE,1968.,50,L,A1,A2,A3,A4)
        ONE=-A3/A4
        TWO=-A1/A4
        THREE=+A2/A4
        L=0
        RETURN
        END
        SUBROUTINE FDG (J,MM,NEXT,DLAT,DLONG,Q,TM,NMX,L,X,Y,Z,F)
C*************************************************************************
C   J.EQ.0      INPUTS LATITUDE & Q=ALTITUDE (KM) RELATIVE TO ELLIPSOID
C               (GEODETIC COORDINATES)
C   J.EQ.0      OUTPUT FIELD COMPONENTS NORTH,EAST,VERTICAL
C               IN GEODETIC COORDINATES
C
C   J.NE.0      LAT.&LONG IN SPHERICAL COORDINATES, Q=GEOCENTRIC RADIUS(KM)
C   J.NE.0      OUTPUT FLD COMPONENTS NORTH,EAST,VERTICAL IN SPHERICAL COOR
C
C   MM.EQ.0     USE DEFAULT VALUES AE=6378.16,FLAT=298.25
C   MM.NE.0     INPUT VALUES FOR AE,FLAT      ON FIRST CALL TO FDG
C
C   NEXT.EQ.0 DO NOT READ INPUT VALUES FOR EXTERNAL FIELD PARAMETERS
C               WHEN L IS GREATER THAN 0
C   NEXT.EQ.0 DO NOT EVALUATE EXTERNAL FIELD FROM MODEL
C   NEXT.NE.0 READ INPUT VALUES FOR EXTERNAL FIELD PARAMETERS WHEN
C               L GREATER 0
C   NEXT.NE.0 EVALUATE EXTERNAL FIELD MODEL
C
C   DLAT        GEODETIC LATITUDE IN DEGREES WHEN J=0
C               GEOCENTRIC LATITUDE IN DEGREES WHEN J=1
C
C   DLONG       LONGITUDE IN DEGREES
C
C   Q           GEODETIC ALTITUDE (KM) WHEN J=0
C               GEOCENTRIC RADIUS (KM) WHEN J=1
C
C   NMAX        MAXIMUM DEGREE AND ORDER OF CONSTANT TERMS OF FIELD MODEL
C   NMAXT          "        "       "  FIRST ORDER TIME        "   "    "
C   NMAXTT         "        "       "  SECOND  "   "           "   "    "
C   NMXTTT         "        "       "  THIRD   "   "           "   "    "
C
C   K.EQ.0      FIELD MODEL COEFFICIENTS SCHMIDT NORMALIZED
C   K.NE.0      FIELD MODEL COEFFICIENTS GAUSS NORMALIZED
C
C   TZERO       EPOCH TIME FOR FIELD MODEL COEFFICIENTS
C
C   ABAR        MEAN RADIUS USED IN FIELD MODEL POTENTIAL EXPANSION
C               (DEFAULT = 6371.2)
C
C   MODEXT.EQ.0 NO EXTERNAL FIELD SOLVED WITH MODEL
C   MODEXT.NE.0 EXTERNAL FIELD SOLVED WITH MODEL
C   L.EQ.0      EVALUATE FIELD
C   L.GT.0      READ IN FIELD MODEL AND EVALUATE FIELD
C   L.LE.0      EVALUATE FIELD AT OLD TIME
C*************************************************************************
        EQUIVALENCE (SHMIT(1,1),TG(1,1)).
```

```
      COMMON /COEFFS/TG(18,18)
      COMMON /FLDCCM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B,
     &ABAR,E1,E2,E3,NEXTF
      DIMENSION G(18,18),GT(18,18),SHMIT(18,18),AID(33)
      DIMENSION GTTT(8,8),GTT(18,18)
      DATA IFRST/0/
      DATA AE,FLAT/6378.16,298.25/
      DATA TLAST/0./
      DATA TABAR/6371.2/
      IF(IFRST) 110,100,110
C
C        EQUATORIAL EARTH RADIUS AND FLATTENING FACTOR
C        USED IN GEODETIC-GEOCENTRIC COORDINATES.
C
C        THE MODEL ITSELF IS INDEPENDENT OF THOSE
C        PARAMETERS
C
  100 IF(MM.NE.0)READ(5,101) AE,FLAT
  101 FORMAT(1X,2F6.1)
      WRITE(6,109) AE,FLAT
  109 FORMAT(//5X,'CONSTANTS USED : '/,22X,'EQUATORIAL EARTH RADIUS   ',
     &F8.3/,22X,'EARTH RECIPROCAL FLATTENING   ',F6.1//)
      IFRST=1
      FLAT=1. -1./FLAT
      E1=0.
      E2=0.
      E3=0.
      A2=AE**2
      A4=AE**4
      B2=(AE*FLAT)**2
      A2B2=A2*(1.-FLAT**2)
      A4B4=A4*(1.-FLAT**4)
  110 IF (L) 19,1,2
1     IF (TM-TLAST) 17,19,17
2     READ (5,3) NMAX,NMAXT,NMAXTT,NMXTTT,MODEXT,K,TZERO,ABAR,
     &(AID(I),I=1,10)
3     FORMAT(4I2,2I2,2F6.1,12A4,A2)
      IF (ABAR.EQ.0.) ABAR=TABAR
      READ(5,103)  (AID(I),I=14,33)
103   FORMAT(20A4)
      L=0
      WRITE (6,104)  (AID(I),I=1,33)
104   FORMAT (25X,12A4,A2/5X,20A4//)
      WRITE(6,105) NMAX,NMAXT,NMAXTT,NMXTTT,MODEXT,K,TZERO,ABAR
 105  FORMAT(5X,'FIELD MODEL ORDER (',I2,',',I2,',',I2,',',I2,')'/,
     &5X,'EXTERNAL FIELD SOLVED WITH MODEL (0-NO; 1-YES)',I2/,
     &5X,'NORMALIZATION (K=0-SCHMIDT : K.NE.0-GAUSS)',I2/,
     &5X,'FIELD MODEL EPOCH   ',F6.1/,
     &5X,'FIELD MODEL MEAN RADIUS  ',F6.1//)
      MAXN=0
      TEMP=0.
5     READ (5,6) N,M,GNM,HNM,GTNM,HTNM,GTTNM,HTTNM
6     FORMAT (2I3,6F11.4)
      IF (N.LE.0) GOTO7
      MAXN=(MAX0(N,MAXN))
      G(N,M)=GNM
      GT(N,M)=GTNM
      GTT(N,M)=GTTNM
      TEMP=AMAX1(TEMP,ABS(GTNM))
      IF (M.EQ.1) GOTO5
      G(M-1,N)=HNM
      GT(M-1,N)=HTNM
      GTT(M-1,N)=HTTNM
      GO TO 5
7     IF(NMXTTT.EQ.0) GO TO 107
106   READ(5,6)N,M,GTTTNM,HTTTNM
      IF (N.EQ.0) GO TO 107
      IF (N.GT.8) STOP 106
      GTTT(N,M)=GTTTNM
      IF (M.EQ.1) GO TO 106
      GTTT(M-1,N)=HTTTNM
      GO TO 106
107   CONTINUE
      IF(MODEXT.NE.0) READ(5,102) E1,E2,E3
102   FORMAT(6X,3F9.2)
      WRITE(6,8)
8     FORMAT(6H0 N  M,6X1HG,10X1HH,9X2HGT,9X2HHT,8X3HGTT,
     &8X3HHTT,7X4HGTTT,7X4HHTTT//)
      DO 12 N=2,MAXN
      DO 12 M=1,N
      MI=M-1
      IF (M.EQ.1) GOTO10
      IF(N.GT.NMXTTT) WRITE(6,9) N,M,G(N,M),G(MI,N),
```

```
     &GT(N,M),GT(MI,N),GTT(N,M),GTT(MI,N)
      IF(N.LE.NMXTTT) WRITE(6,9)N,M,G(N,M),G(MI,N),
     &GT(N,M),GT(MI,N),GTT(N,M),GTT(MI,N),GTTT(N,M),GTTT(MI,N)
9     FORMAT(2I3,8F11.4)
      GO TO 12
10    CONTINUE
      IF(N.GT.NMXTIT) WRITE(6,11)N,M,G(N,M),GT(N,M),
     &GTT(N,M)
      IF(N.LE.NMXTTT) WRITE(6,11)N,M,G(N,M),GT(N,M),
     &GTT(N,M),GTTT(N,M)
11    FORMAT(2I3,F11.4,11X,F11.4,11X,F11.4,11X,F11.4)
12    CONTINUE
      IF(MODEXT.NE.0)WRITE(6,108) E1,E2,E3
108   FORMAT(//5X,8HEXTFLD, ,3F10.2)
13    FORMAT (1H1)
      IF (TEMP.EQ.0.) L=-1
14    IF (K.NE.0) GOTO17
      SHMIT(1,1)=-1.
      DO 15 N=2,MAXN
      SHMIT(N,1)=SHMIT(N-1,1)*FLOAT(2*N-3)/FLOAT(N-1)
      SHMIT(1,N)=0.
      JJ=2
      DO 15 M=2,N
      SHMIT(N,M)=SHMIT(N,M-1)*SQRT(FLOAT((N-M+1)*JJ)/FLOAT(N+M-2))
      SHMIT(M-1,N)=SHMIT(N,M)
15    JJ=1
      DO 16 N=2,MAXN
      DO 16 M=1,N
      G(N,M)=G(N,M)*SHMIT(N,M)
      GT(N,M)=GT(N,M)*SHMIT(N,M)
      GTT(N,M)=GTT(N,M)*SHMIT(N,M)
      IF(NMXTTT.GT.0.AND.N.LE.8) GTTT(N,M)=GTTT(N,M)*SHMIT(N,M)
      IF (M.EQ.1) GOTO16
      G(M-1,N)=G(M-1,N)*SHMIT(M-1,N)
      GT(M-1,N)=GT(M-1,N)*SHMIT(M-1,N).
      GTT(M-1,N)=GTT(M-1,N)*SHMIT(M-1,N)
      IF(NMXTTT.GT.0.AND.N.LE.8) GTTT(M-1,N)=GTTT(M-1,N)*SHMIT(M-1,N)
16    CONTINUE
17    T=TM-TZERO
      DO 18 N=1,MAXN
      DO 18 M=1,N
      TGX=0.
      THX=0.
      IF(M.EQ.1) GO TO 270
      IF(N.GT.NMXTTT) GO TO 210
      TGX=GTTT(N,M)*T
      THX=GTTT(M-1,N)*T
210   IF(N.GT.NMAXTT) GO TO 220
      TGX=(TGX + GTT(N,M))*T
      THX= (THX + GTT(M-1,N))*T
220   IF(N.GT.NMAXT) GO TO 230
      TGX=(TGX + GT(N,M))*T
      THX=(THX+GT(M-1,N))*T
230   TGX=TGX+G(N,M)
      THX=THX+G(M-1,N)
      TG(N,M)=TGX
      TG(M-1,N)=THX
      GO TO 18
270   CONTINUE
      IF(N.GT.NMXTTT) GO TO 240
      TGX=GTTT(N,M)*T
240   IF(N.GT.NMAXTT) GO TO 250
      TGX=(TGX+GTT(N,M))*T
250   IF(N.GT.NMAXT) GO TO 260
      TGX=(TGX+GT(N,M))*T
260   TGX= TGX+G(N,M)
      TG(N,M)=TGX
18    CONTINUE
      TLAST=TM
19    DLATR=DLAT/57.2957795D0
      SINLA=SIN(DLATR)
      RLONG=DLONG/57.2957795D0
      CPH=COS(RLONG)
      SPH=SIN(RLONG)
      IF (J.EQ.0) GOTO20
C
C         Q IS GEOCENTRIC RADIUS WHEN J=1
C
      R=Q
      CT=SINLA
      GO TO 21
20    SINLA2=SINLA**2
C
```

```
C
C          Q IS GEODETIC ALTITUDE WHEN J=0
C          ALT=Q
C
      COSLA2=1.-SINLA2
      DEN2=A2-A2B2*SINLA2
      DEN=SQRT(DEN2)
      FAC=(((Q*DEN)+A2)/((Q*DEN)+B2))**2
      CT=SINLA/SQRT(FAC*COSLA2+SINLA2)
      R=SQRT(Q*(Q+2.*DEN)+(A4-A4B4*SINLA2)/DEN2)
21    ST=SQRT(1.-CT**2)
      NMAX=MIN0(NMX,MAXN)
      NEXTF=NEXT
      CALL MAGF
      Y=BP
      F=B
      IF (J) 22,23,22
22    X=-BT
      Z=-BR
      RETURN
C     TRANSFORMS FIELD TO GEODETIC DIRECTIONS
23    SIND=SINLA*ST-SQRT(COSLA2)*CT
      COSD=SQRT(1.0-SIND**2)
      X=-BT*COSD-BR*SIND
      Z=BT*SIND-BR*COSD
      RETURN
      END
      SUBROUTINE MAGF
      COMMON /COEFFS/G(18,18)
      COMMON/FLDCOM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B,ABAR,E1,E2,E3,NEXT
      DIMENSION P(18,18),DP(18,18),CONST(18,18),SP(18),CP(18),FN(18),FM(
     118)
      IF (P(1,1).EQ.1.0) GO TO 3
1     P(1,1)=1.
      DP(1,1)=0.
      SP(1)=0.
      CP(1)=1.
      DO 2 N=2,18
      FN(N)=N
      DO 2 M=1,N
      FM(M)=M-1
2     CONST(N,M)=FLOAT((N-2)**2-(M-1)**2)/FLOAT((2*N-3)*(2*N-5))
3     SP(2)=SPH
      CP(2)=CPH
      DO 4 M=3,NMAX
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
4     CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
      AOR=ABAR/R
      AR=AOR**2
      BT=0.
      BP=0.
      BR=0.
      DO 8 N=2,NMAX
      AR=AOR*AR
      DO 8 M=1,N
      IF (N-M) 6,5,6
5     P(N,N)=ST*P(N-1,N-1)
      DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)
      GO TO 7
6     P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)
C
C          NOTE : CONST(2,1)=0
C
      DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)
7     PAR=P(N,M)*AR
      IF (M.EQ.1) GO TO 9
      TEMP=G(N,M)*CP(M)+G(M-1,N)*SP(M)
      BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR
      GO TO 10
9     TEMP=G(N,M)*CP(M)
10    BT=BT+TEMP*DP(N,M)*AR
8     BR=BR-TEMP*FN(N)*PAR
      BP=BP/ST
C     IF(NEXT.GT.0) CALL EXTFLD
      B=SQRT(BT*BT+BP*BP+BR*BR)
      RETURN
      END
      SUBROUTINE DATA
      COMMON/DAT/B(60,31),T(60,31),P(60,31),R(60,31)
      DO 1 I=1,31
    1 READ (14,12) (B(J,I),J=1,60)
      DO 2 I=1,31
    2 READ (16,12) (T(J,I),J=1,60)
      DO 3 I=1,31
```

```
3     READ (18,12) (P(J,I),J=1,60)
      DO 4 I=1,31
4     READ (20,12) (R(J,I),J=1,60)
12    FORMAT (11F7.2)
      RETURN
      END
      SUBROUTINE FUN(JOPT)
       DIMENSION BX(50),BY(50),BS(50),C(50),S(50),X(50),Y(50)
      COMMON /BLK/NMBR(5),XX(5,50),YY(5,50),NPSM
      COMMON/BWC/P(14),DFDP1(14),DFDP2(14),DFDP3(14),
     *DFDP4(14),XF,YF,ZF,FR,FT,FP,YC,NP,ND,Z1,Z2
      REAL*8 D,DFDP1,DFDP2,DFDP3,DFDP4,DFDP,DW,DP,SUMD,DC,DCC
      REAL*4 LL,M,N
      AINC=70.
      DEC=-5.
      FR=0.
      FT=0.
      FP=0.
      YC=0.
      DZ=Z2-Z1
      Z1F=Z1 - ZF
      Z2F=Z2 - ZF
      DO 57 II=1,ND
C     WRITE(6,40) II,NPSM,XF,YF
40    FORMAT(2I3,2F8.2)
       L=(II-1)*3
      NBP=NMBR(II)
      NB1=NBP+1
      YY(II,NB1)=YY(II,1)
      XX(II,NB1)=XX(II,1)
      DO 1 I=1,NBP
      BY(I)=XX(II,I+1)-XX(II,I)
      BX(I)=YY(II,I+1)-YY(II,I)
      BS(I)=SQRT(BX(I)*BX(I)+BY(I)*BY(I))
C     WRITE(6,50) I,NBP,XX(II,I+1),XX(II,I),BS(I),YY(II,I+1),YY(II,I)
50    FORMAT(2I3,5F10.2)
      C(I)=BY(I)/BS(I)
      S(I)=BX(I)/BS(I)
    1 CONTINUE
      DO 2 I=1,NB1
      Y(I)=XX(II,I)-XF
      X(I)=YY(II,I)-YF
    2 CONTINUE
      V1=0.
      V2=0.
      V3=0.
      V4=0.
      V5=0.
      V6=0.
      DO 3 I=1,NBP
      X1=X(I)
      X2=X(I+1)
      Y1=Y(I)
      Y2=Y(I+1)
      DX=BX(I)
      DY=BY(I)
      DS=BS(I)
      R1=SQRT(X1*X1+Y1*Y1)
      R2=SQRT(X2*X2+Y2*Y2)
      R11=SQRT(R1*R1+Z1F*Z1F)
      R12=SQRT(R1*R1+Z2F*Z2F)
      R21=SQRT(R2*R2+Z1F*Z1F)
      R22=SQRT(R2*R2+Z2F*Z2F)
      D1=(X1*DX+Y1*DY)/DS
      D2=(X2*DX+Y2*DY)/DS
      PP=(X1*Y2-X2*Y1)/DS
      T11=R11+D1
      T12=R12+D1
      T21=R21+D2
      T22=R22+D2
      F11=R11+Z1F
      F12=R12+Z2F
      F21=R21+Z1F
      F22=R22+Z2F
      S2=S(I)*S(I)
      C2=C(I)*C(I)
      SC=S(I)*C(I)
C     WRITE(6,47) DS,F12,F21,T12,T21,Z1,Z2,PP,R11,R22,R12,R21,I,NBP
47    FORMAT(12(F8.2),2I3)
      F=ALOG(F22*F11/(F12*F21))
      Q=ALOG(T22*T11/(T12*T21))
      W=0.
      IF(PP.EQ.0.) GC TO 11
```

```
      W=ATAN (Z2F*D2/(PP*R22))-ATAN (Z2F*D1/(PP*R12))-
     *ATAN (Z1F*D2/(PP*R21))+ATAN (Z1F*D1/(PP*R11))
 11   CONTINUE
      V1=V1+SC*F-C2*W
      V2=V2+SC*W+C2*F
      V3=V3+C(I)*Q
      V4=V4-SC*F-S2*W
      V5=V5-S(I)*Q
      V6=V6+W
 3    CONTINUE
C
      IF(JOPT.EQ.1) GO TO 12
C
C     FOR ESTIMATING SOURCE COMPONENTS
C
      DFDP1 (L+1) =V5
      DFDP1 (L+2) =V3
      DFDP1 (L+3) =V6
      DFDP2 (L+1) =V2
      DFDP2 (L+2) =V1
      DFDP2 (L+3) =V3
      DFDP3 (L+1) =V4
      DFDP3 (L+2) =V2
      DFDP3 (L+3) =V5
      DFDP4 (L+1) =LL*V2+M*V4+N*V5
      DFDP4 (L+2) =LL*V1+M*V2+N*V3
      DFDP4 (L+3) =LL*V3+M*V5+N*V6
      FR=P (L+2) *V3+P (L+1) *V5+P (L+3)*V6  + FR
      FP=P (L+2) *V2+P (L+1) *V4+P (L+3) *V5  + FP
      FT=P (L+2) *V1+P (L+1) *V2+P (L+3) *V3  + FT
      YC=P (L+1) *DFDP4 (L+1) +P (L+2) *DFDP4 (L+2) +P (L+3) *DFDP4 (L+3)+YC
      GO TO 31
 12   CONTINUE
C
C     FOR ESTIMATING SOURCE MAGNITUDES
C
      DFDP1 (II)= (LL*V3+M*V5+N*V6)
      DFDP3 (II)= (LL*V2+M*V4+N*V5)
      DFDP2 (II)= (LL*V1+M*V2+N*V3)
      DFDP4 (II)=LL*(LL*V1+M*V2+N*V3) +M* (LL*V2+M*V4+N*V5) +
     * N*(LL*V3+M*V5+N*V6)
      FR=P (II) *DFDP1 (II) +FR
      FT=P (II) *DFDP2 (II) +FT
      FP=P (II) *DFDP3 (II) +FP
      YC=P (II) *DFDP4 (II) +YC
 31   CONTINUE
C      WRITE(6,707) II,DFDP1(II),DFDP2(II),DFDP3(II),DFDP4(II),
C    *  LL,M,N,V1,V2,V3,V4,V5,V6,F,Q,W,PP
C707   FORMAT(I4,4F7.2,3F6.2,6F6.2,4F5.1)
 57   CONTINUE
      RETURN
      ENTRY ANGL
       AINC=70.
       DEC=-5.
      ARC=.0174533
      LL=COS (AINC*ARC) *COS (DEC*ARC)
      M=COS (AINC*ARC) *SIN (DEC*ARC)
      N=SIN (AINC*ARC)
      RETURN
      END
      SUBROUTINE MAGVEC (J,I,PX,PY,PZ,PHI,PI,PD,SIGPHI)
          REAL*8  DNORMX(1)
          DIMENSION  ECOV (3,3) ,A(3)
          COMMON/DMAT/DNORMX
          COMMON/POS/ND,XLAT(4) ,YLON(4)
          LOC(II,JJ,NDIM)=(JJ-1)*NDIM  -(JJ**2-JJ)/2  + II
      ARC=.0174533
      FI=70.
      FD=-5.
      P=SQRT(PX**2+PY**2+PZ**2)
      PI=ARSIN (PZ/P)
      PD=ARSIN (PY/(P*COS(PI)))
      FZ=SIN ((FI) * (ARC))
      FY=COS ((FI) * (ARC)) *SIN ((FD) * (ARC))
      FX=SQRT(1.-FY**2-FZ**2)
      PHI=ARCOS((FX*PX+FY*PY+FZ*PZ)/P)
      PI=(PI)/(ARC)
      PD=(PD)/(ARC)
      PHI=(PHI)/(ARC)
          B1=PY/P
          B2=PX/P
          B3=PZ/P
          CNE=XLAT(J)
```

```
             TWO=YLON(J)
             THREE=6371.2
             IP=I
             IP3=I + 2
             DO 20 IC=IP,IP3
             DO 20 JC=IP,IP3
             LC=LOC(IC,JC,ND)
             IF(IC.LE.JC) LC=LOC(JC,IC,ND)
C            WRITE(6,996) IC,JC,LC,DNORMX(LC)
  995        FORMAT('    PCOV MATRIX ',3I10,G20.12)
   20         PCOV(IC-IP +1,JC-IP+1)=DNORMX(LC)
C             WRITE(6,990) J,I,ND,XLAT(J),YLON(J)
C            WRITE(6,995) (DNORMX(KK),KK=1,45)
  990        FORMAT('    MAGVEC .990  ',3I10,2F8.2)
  995            FORMAT(10X,8E15.3)
             CALL FLD(ONE,TWO,THREE)
             COSP=(-ONE*PZ - TWO*PX + THREE*PY)/P
             SINP=SQRT(1. - COSP*COSP)
             A(1)=(THREE - COSP*B1)/(P*SINP)
             A(2)=(-TWO - COSP*B2)/(P*SINP)
             A(3)=(-ONE - COSP*B3)/(P*SINP)
             SIGPHI=0.
             DO 12 L=1,3
             DO 14 K=1,3
   14          SIGPHI=SIGPHI + A(K)*PCOV(K,L)*A(L)
   12         CONTINUE
             SIGPHI=SQRT(SIGPHI)/.0174533
             A(1)=B1
             A(2)=B2
             A(3)=B3
             SIGMAG=0.
             DO 16 L=1,3
             DO 16 K=1,3
   15         SIGMAG=SIGMAG + A(K)*PCOV(K,L)*A(L)
             WRITE(6,900) J,I,COSP,SIGPHI,SIGMAG
  900        FORMAT(10X,'MAGVEV.900  ',2I10,3F10.2)
             RETURN
             END
      SUBROUTINE CORLPR(D,S,NOR,NT)
      REAL*8 D(1),S(1),COVMIN
C      K=PTR IN D  I=ROW PTR  J=COL PTR
C      D ARRAY HOLDS NORMAL EQUATIONS OR COVARIANCE MATRIX
C      S IS PRINTOUT ARRAY
C
            IF(NT.EQ.0) GO TO 320
      DO 300 J=1,NOR
      LC=(J-1)*NOR-(J*J-3*J)/2-1
      DO 300 M=J,NOR
      LC=LC+1
  300 D(LC)=D(LC)/DSQRT(S(M)*S(J))
  320        CONTINUE
C
      K=1
      WRITE(6,720) K
      WRITE(6,730) D(K)
      DO 400 J=2,NOR
      K=J
      DO 350 I=1,J
       S(I)=D(K)
  350  K=K+NOR-I
      WRITE(6,720) J
      WRITE(6,730)  (S(I),I=1,J)
  400 CONTINUE
      RETURN
  720 FORMAT(/' J =',I5)
  730 FORMAT(' ',13F10.2)
      END
      SUBROUTINE TSINV(LL,MM,A,R)
            DOUBLE PRECISION DPIV,DSUM,A2,R(1).,A(1)
      IDIGL=0
      LTROW=1
      IF(LL.LT.1)GO TO 900
      LL1=LL-1
      K1=0
      LM=MM-LL
      IND=-LM
      DO 90 K=1,LL
      IND=IND+LM
      KPIV=IND+1
      LEND=K-1
      TOL=A(KPIV)
      DO 80 I=K,LL
      IND=IND+1
```

```
      DSUM=0.D0
      IF (LEND) 30,30,10
10    LANF=K
      LIND=I-K
      DO 20 L=1,LEND
      DSUM=DSUM+A(LANF)*A(LANF+LIND)
      LANF=LANF+NM-L
20    CONTINUE
30    DSUM=A(IND)-DSUM
      IF (I.NE.K) GO TO 70
      IF (DSUM) 900,900,40
40    CONTINUE
      IDIG=ALOG10(TOL/SNGL(DSUM))-.5
      IF (IDIG.LE.IDIGL) GO TO 60
      IDIGL=IDIG
      LTROW=I
50    DPIV=DSQRT(DSUM)
      A1=(1.D0/DPIV)
      A2=(1.D0-DBLE(A1)*DPIV)/DPIV
      A(IND)=DPIV
      B(K)=DPIV
      GO TO 80
70    A(IND)=A2*DSUM+DBLE(A1)*DSUM
80    CONTINUE
90    CONTINUE
      DO 152 K=1,LL
      DPIV=A(KPIV)
      A1=(1.D0/DPIV)
      A2=(1.D0-DBLE(A1)*DPIV)/DPIV
      A(KPIV)=A2+DBLE(A1)
      B(LL-K+1)=A(KPIV)
      LEND=K-1
      IF (LEND) 130,130,110
110   DO 120 L=1,LEND
      IND=KPIV+L
      A(IND)=-(A2*A(IND)+DBLE(A1)*A(IND))
120   CONTINUE
130   IF (K.EQ.LL) GO TO 152
      IND=KPIV
      KPIV=KPIV-LM-1-K
      LANF=IND
      DO 151 I=K,LL1
      LANF=LANF-LM-I
      DSUM=A(LANF)
      A(LANF)=A2*DSUM+DBLE(A1)*DSUM
      IF (LEND) 151,151,140
140   DO 150 L=1,LEND
      LIND=LANF+L
      A(LIND)=A(LIND)+DSUM*A(IND+L)
150   CONTINUE
151   CONTINUE
152   CONTINUE
      DO 180 K=1,LL
       LIND=KPIV-1
       LANF=KPIV
       DO 170 I=K,LL
      DSUM=0.D0
      DO 160 L=KPIV,IND
      LIND=LIND+1
      DSUM=DSUM+A(L)*A(LIND)
160   CONTINUE
      A(KPIV)=DSUM
      LIND=LIND+LM
      KPIV=KPIV+1
170   CONTINUE
      B(K)=0.D0
      KPIV=KPIV+LM
      IND=IND+MM-K
180   CONTINUE
          WRITE(6,921) IDIGL,LTROW
921    FORMAT(//2X,'****** TSINV ******',2X,2I7//)
      RETURN
900   IDIGL=-1
      LTROW=I
      WRITE(6,920) LTROW
920   FORMAT(5X,'* * * *     INVERSION FAILED AT ROW',I6)
      STOP 13
      RETURN
      END
/*
// EXEC OLINKGOH,REGION.GO=500K
//GO.FT05F001 DD DSN=F9#MG.GMCOEF(PO3Q0272),DISP=SHR,LABEL=(,,,IN)
//          DD DSN=ICDMM.INVERT.AREA(LQC60X32),DISP=SHR,LABEL=(,,,IN)
```

```
//      DD DSN=YCDMM.INVERT.AREA(DELTAT),DISP=SHR,LABEL=(,,,IN)
//GO.FT12F001 DD DSN=YCDMM.SCOT(MOSAIC),DISP=SHR,LABEL=(,,,IN)
//GO.FT14F001 DD DSN=YIMAM.US.AREA.DB.DATA,DISP=SHR,LABEL=(,,,IN)
//GO.FT16F001 DD DSN=YIMAM.US.AREA.DX.DATA,DISP=SHR,LABEL=(,,,IN)
//GO.FT18F001 DD DSN=YIMAM.US.AREA.DY.DATA,DISP=SHR,LABEL=(,,,IN)
//GO.FT20F001 DD DSN=YIMAM.US.AREA.DZ.DATA,DISP=SHR,LABEL=(,,,IN)
// EXEC NOTIFYTS
```

TABLE CAPTIONS

Table 1 Summary of regional prismatic model computations using a simple prism model (Figure 10) for the Kentucky body geometry.

Table 2 Summary of regional prismatic model computations using a detailed prism Figure 11) model for the Kentucky body geometry.

Table 3 Summary of Mosaic Dipole array model computations using the regional geometry shown in Figure 17.

TABLE 1

FLAT EARTH
SIMPLE PRISM

Parameters Solved For		Data Types Used				Region	Magnitude of Magnetization Vector ($\vec{P}$) $\lvert\vec{P}\rvert$	Standard Deviation of $\lvert\vec{P}\rvert$ σp	Angle Between $\vec{P}$ and the Direction of the Main Field ϕ	Standard Deviation of ϕ $\sigma\Phi$
Source Magnitudes	Source Components	ΔB_r	ΔB_θ	ΔB_ϕ	ΔB					
						1	- .3	.7	-	
X					X	2	-16.2	.8	-	
						3	792.0	3.6	-	
						1	- 1.4	.6	-	
X		X	X	X		2	-15.3	.6	-	
						3	731.5	3.0	-	
						1	- .9	.5	-	
X		X	X	X	X	2	-15.4	.6	-	
						3	750.1	2.7	-	
						1	13.9	7.5	87.2	10.8
	X				X	2	68.0	10.6	110.3	4.3
						3	878.6	16.5	13.6	1.6
						1	16.2	1.1	40.0	3.0
	X	X	X	X		2	42.5	2.1	106.4	1.1
						3	854.8	10.4	7.2	.9
						1	12.2	1.0	40.1	3.2
	X	X	X	X	X	2	38.7	1.8	111.0	1.3
						3	845.7	8.5	8.4	.8

TABLE 2

FLAT EARTH

DETAILED PRISM

Parameters Solved For		Data Types Used				Region	Magnitude of Magnetization Vector ($\vec{P}$) $\lvert\vec{P}\rvert$	Standard Deviation of $\lvert\vec{P}\rvert$ σp	Angle Between $\vec{P}$ and the Direction of the Main Field Φ	Standard Deviation of Φ $\sigma\Phi$
Source Magnitudes	Source Components	ΔB_r	ΔB_θ	ΔB_ϕ	ΔB					
						1	- 6.7	.7	-	
X					X	2	-17.0	.8	-	
						3	320.3	2.3	-	
						1	- 1.8	.6	-	
X		X	X	X		2	-16.0	.6	-	
						3	292.7	1.9	-	
						1	- 1.3	.5	-	
X		X	X	X	X	2	-16.1	.6	-	
						3	301.2	1.7	-	
						1	8.5	3.7	111.3	25.1
	X				X	2	61.3	9.8	112.7	5.0
						3	348.1	6.4	13.8	1.7
						1	15.0	1.1	48.5	3.6
	X	X	X	X		2	39.3	2.1	107.2	1.3
						3	337.6	4.0	8.5	1.0
						1	11.2	1.0	51.4	4.3
	X	X	X	X	X	2	35.8	1.8	112.1	1.5
						3	334.3	3.3	9.5	.9

TABLE 3 MOSAIC DIPOLE

Parameters Solved For		Data Types Used				Region	Magnitude of Magnetization Vector ($\vec{P}$) $\lvert\vec{P}\rvert$	Standard Deviation of $\lvert\vec{P}\rvert$ σp	Angle Between $\vec{P}$ and the Direction of the Main Field ϕ	Standard Deviation of ϕ $\sigma\phi$
Source Magnitudes	Source Components	ΔB_r	ΔB_θ	ΔB_ϕ	ΔB					
						1	4.6	.7	-	
X					X	2	-18.2	.7	-	
						3	420.6	2.6	-	
						1	1.8	1.5	-	
X		X	X	X		2	-21.0	1.5	-	
						3	409.7	5.3	-	
						1	4.4	.7	-	
X		X	X	X	X	2	-18.4	.7	-	
						3	420.0	2.6	-	
						1	14.6	1.0	32.0	4.1
	X				X	2	40.2	1.1	138.0	1.0
						3	481.6	9.4	17.0	1.1
						1	13.9	4.0	59.0	16.7
	X	X	X	X		2	36.1	4.0	140.0	4.9
						3	462.9	36.9	14.0	4.6
						1	14.4	1.0	34.0	4.0
	X	X	X	X	X	2	39.9	1.0	137.0	1.0
						3	480.1	9.1	17.0	1.1

FIGURE CAPTIONS

Figure 1 Equivalent source representation of the magnetic anomaly field at height of 325 km derived from Magsat data. Units are nT. Albers equal area projection.

Figure 2 Apparent magnetization contrast in 40km thick layer, obtained from Magsat data. Contour interval is 0.1 A/m. Albers equal area projection.

Figure 3a Bouguer gravity in the vicinity of the Kentucky body. Contour interval 6 mgal. Refraction profiles in fence diagram form from Warren (1968); depth scale marked off in 10km intervals. Inferred position of Grenville Front in heavy dashed line. Light dashed line is aeromagnetic low from Figure 3b. From Mayhew et al (1982).

Figure 3b Aeromagnetic anomaly contours in same area as Figure 3a. Values are hundreds of nT, contour interval 400 nT. Relative to arbitrary datum. -30 mgal contour from Figure 3a shown. From Mayhew et al (1982).

Figure 4 Geometry of model Kentucky body; three regions discussed in text are indicated. Angled boundary shown indicates area of Figure 3.

Figure 5 Computed Bouguer gravity due to model Kentucky body. Contour interval 6 mgal. Compare with Figure 3a.

Figure 6 Computed magnetic anomaly due to model Kentucky body with arbitrary datum shift. Contour interval 400 nT. Contour values are hundreds of nT. Compare with Figure 3b.

Figure 7 Magnetic anomaly due to Kentucky body at satellite altitude. Contour interval 1 nT.

Figure 8 Light broken line is one contour line selcted from aeromagnetic map of Zietz (1982) to indicate extent of highly magnetic source region. Heavy solid line is -30 mgal gravity contour to indicate extend of Kentucky body (KYB).

Figure 9 Tectonic elements in region surrounding Kentucky body. -20 and -30 mgal gravity contours from DOD compilation shown as heavy solid lines to indicate significant highs (h). Cincinnati Arch delineated by zero level structure contour (dot-dash line) on top of Trenton (USGS and AAPG, 1962). Heavy long-dash line is inferred position of Grenville Front. Generalized faults of 38th Parallel Lineament principally from U.S. Geologic Map and Ammerman and Keller (1979). RCG is "Rough Creek Graen" (Soderberg and Keller, 1981). Other symbols are as follows. WL = "Woodward's Line", ECGH = East Continent Gravity High, MMGH = Mid-Michigan Gravity High, LFZ = Lexington Fault Zone, JD = Jessamine Dome, PMT = Pine Mountain Thrust. Position of Kentucky body as delineated by gravity contours labeld KYB. Aeromagnetic lineament shown as short dash line. Small circles are selected basement core locations. Solid circles are medium- to high-grade metamorphics. Open circles are felsic volcanics; circles with dots are basalts. Core samples of low-grade metamorphics, sedimentary rocks, and plutonic rocks not shown. From Mayhew et al (1982).

Figures 10-12 Blackened areas refer to first, second, and third model source regions, respectively, referred to in text.

Figure 13 Magnetic anomaly in the total field due to source region two (Figure 11) computed at 325 km for unconstrained magnetization direction.

Figure 14 As Figure 13 for magnetization direction constrained to be in main field direction.

Figure 15 As Figure 14, but for region three (Figure 12).

Figure 16 Difference between data of Figure 1 and data of Figure 15. Map shows anomaly in the total field without the effect of the extended source region.

Figure 17 Geometry showing dipole locations and mosaic regions I (•), II (+) and III (Δ) for the dipole array models.

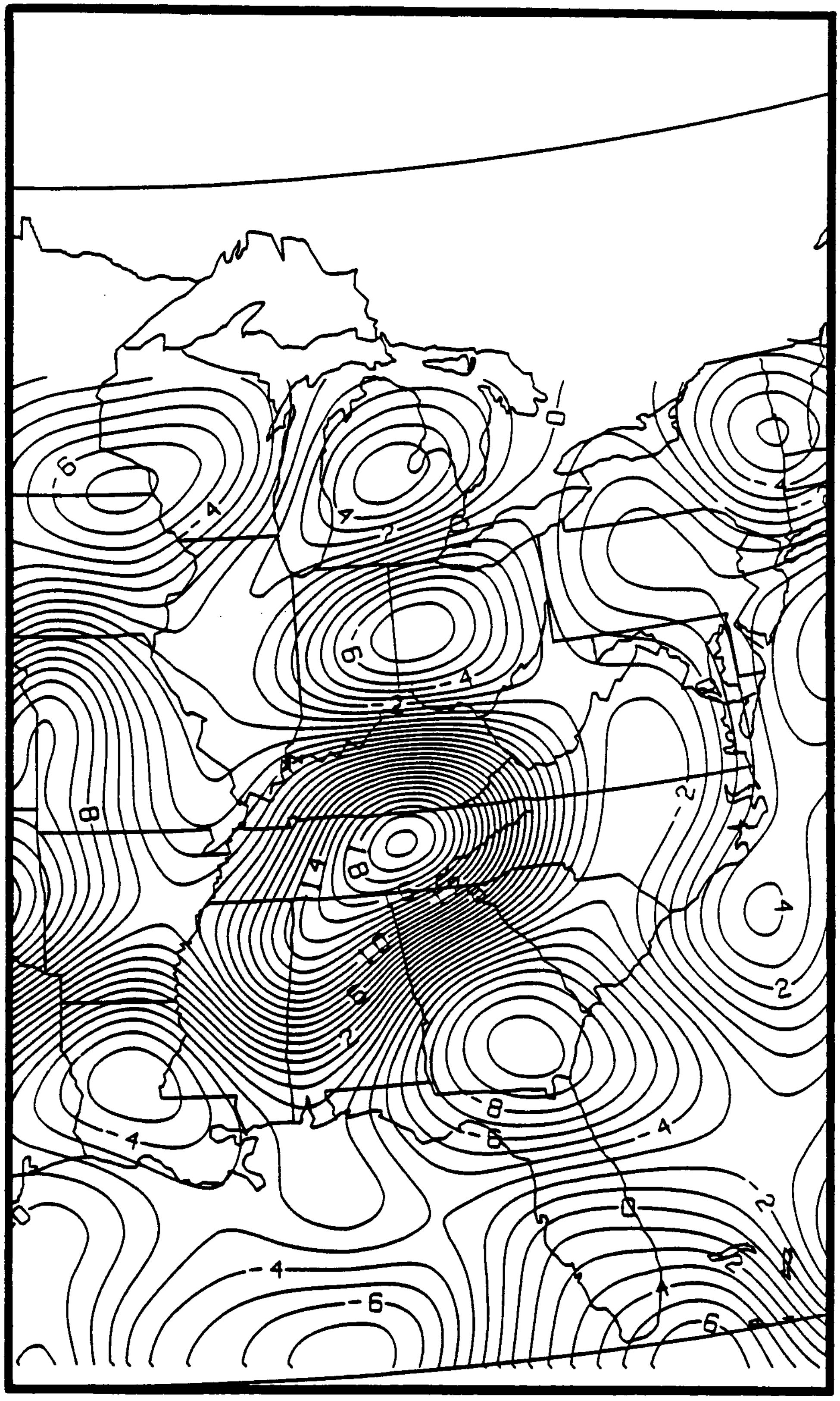


FIGURE 1

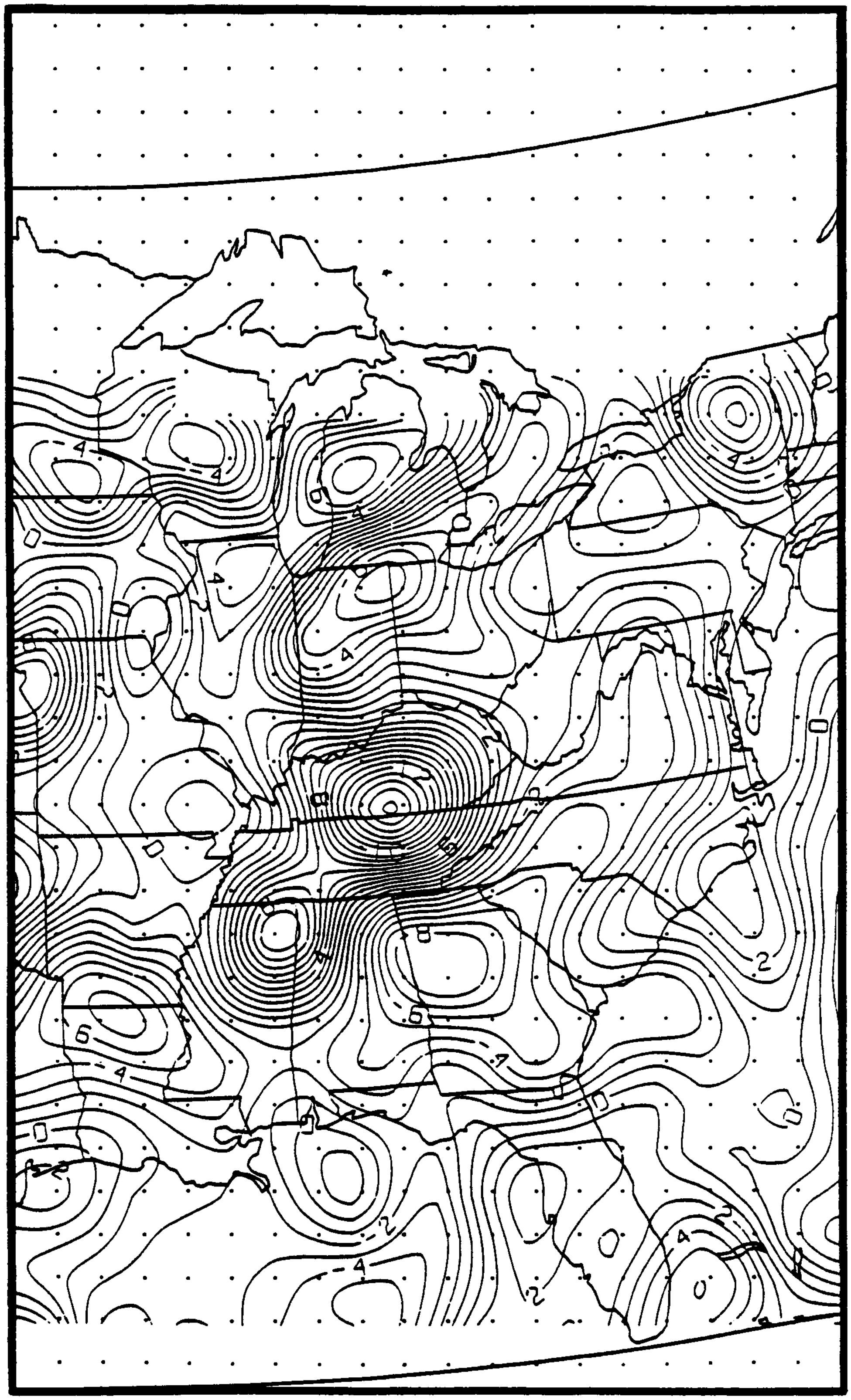


FIGURE 2

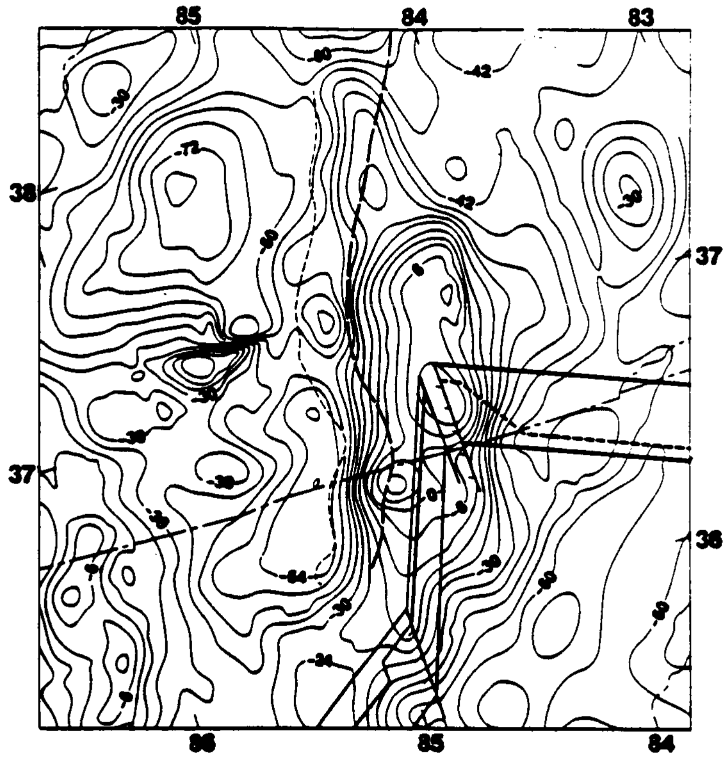


FIGURE 3a

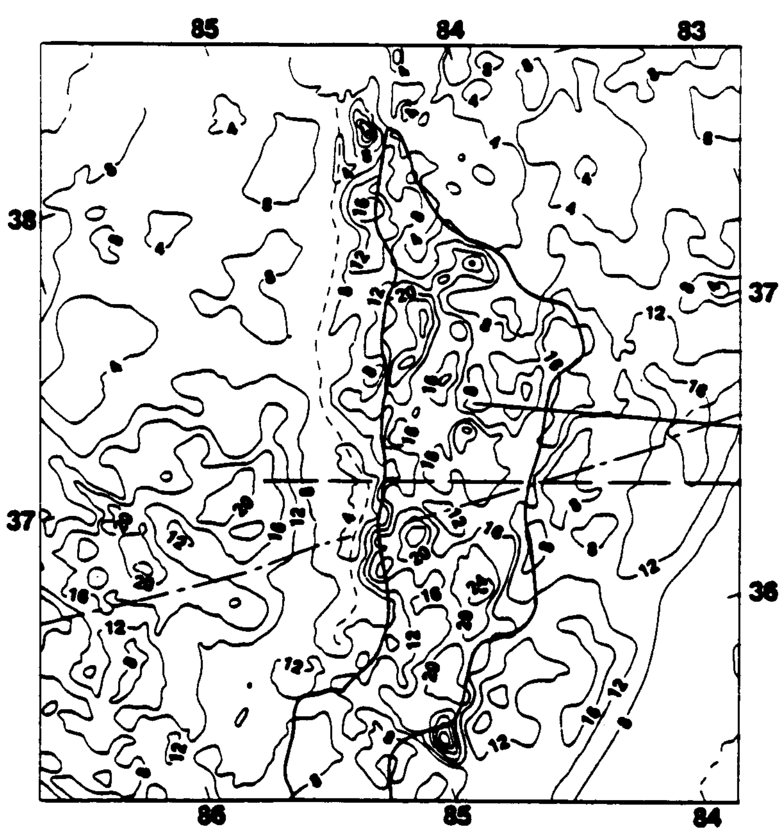


FIGURE 3b

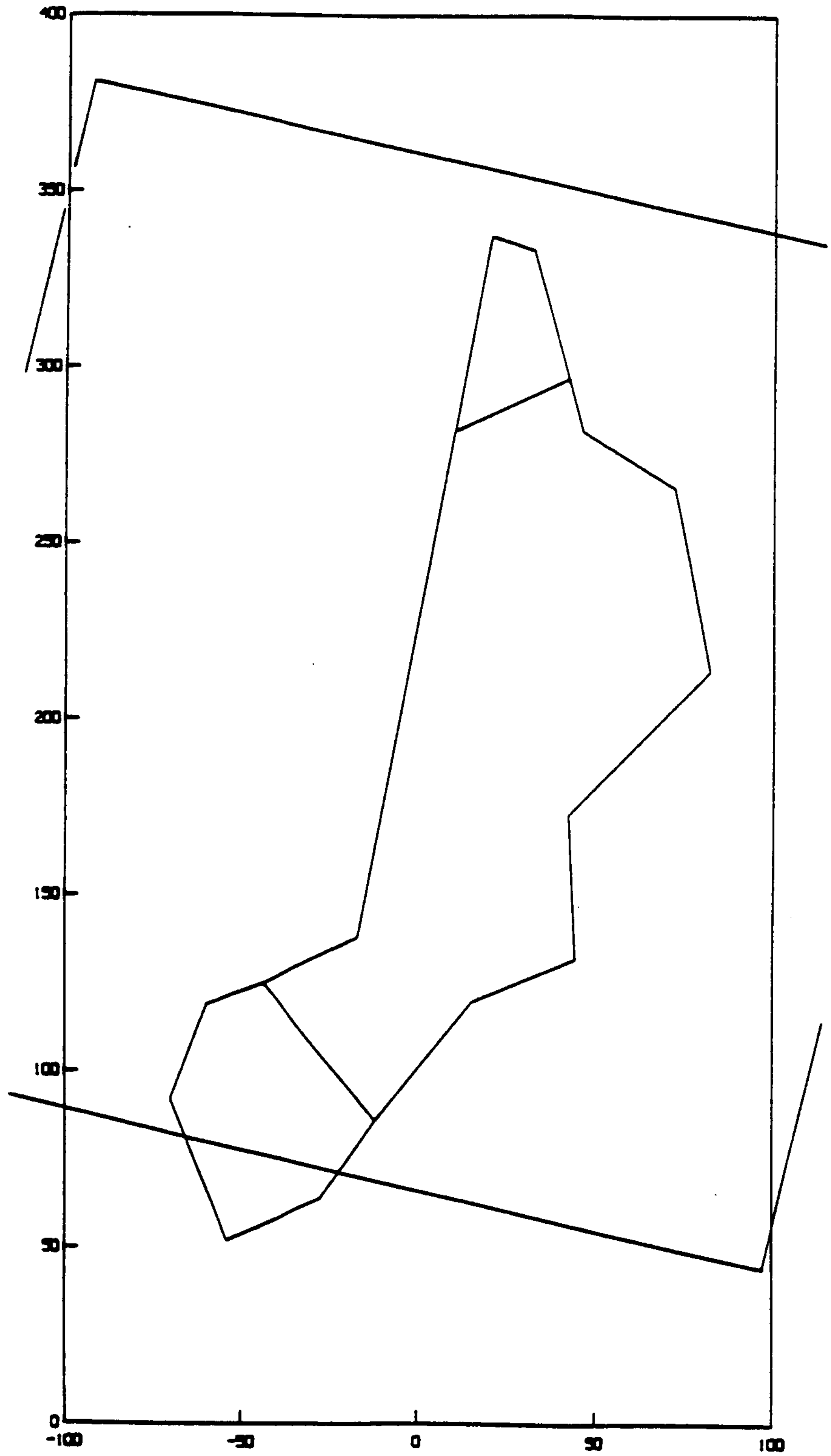


FIGURE 4

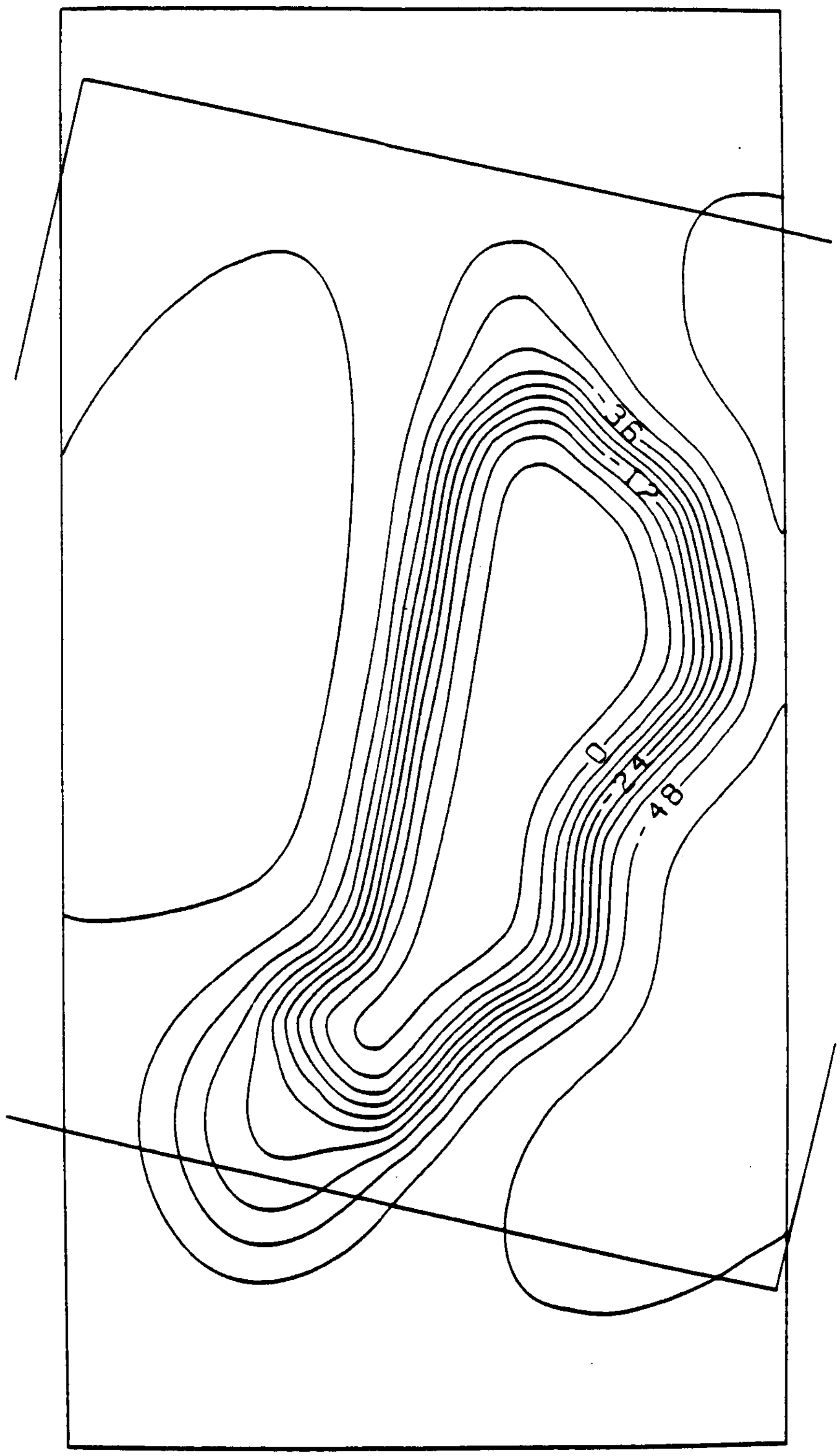


FIGURE 5

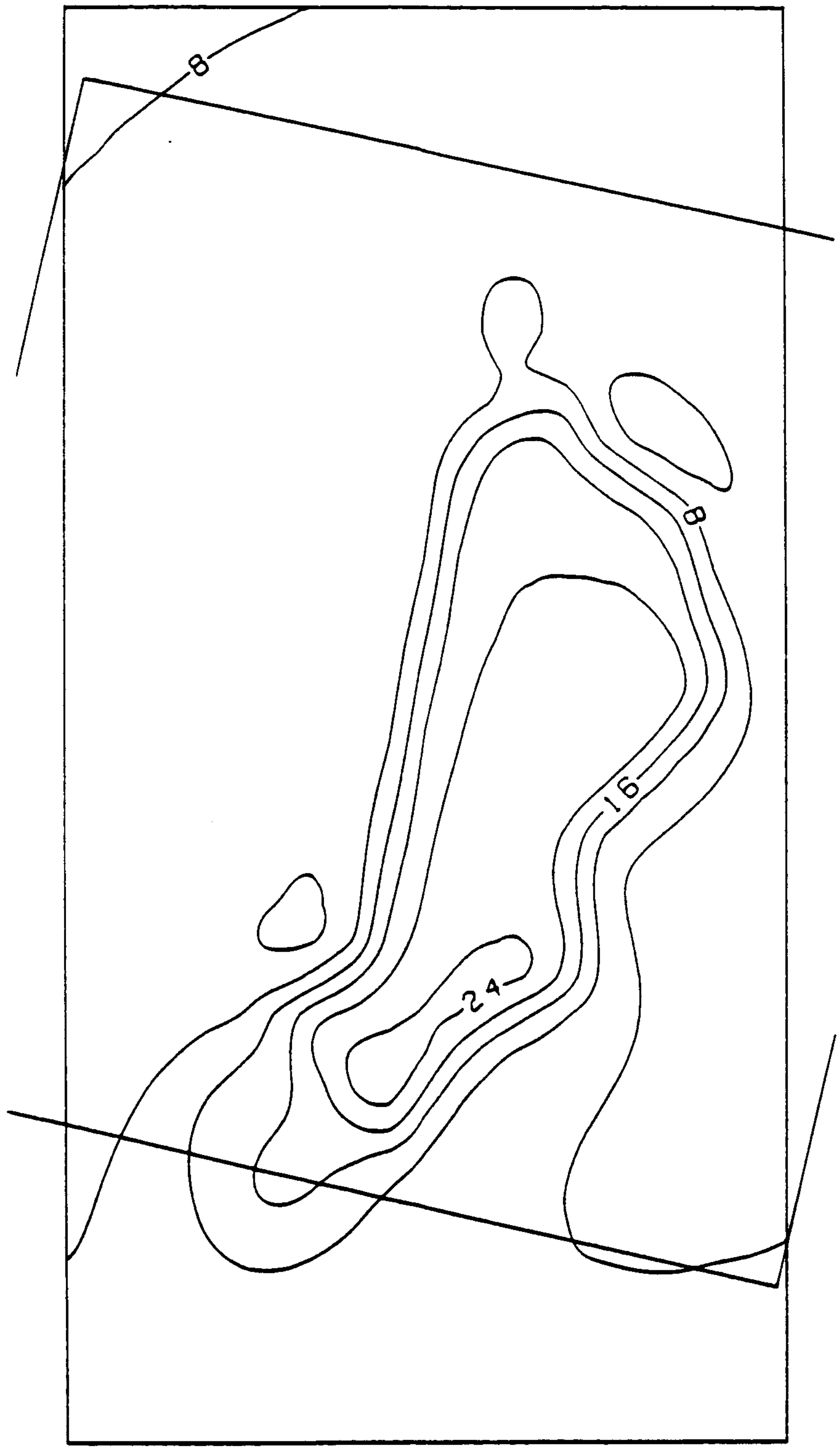


FIGURE 6

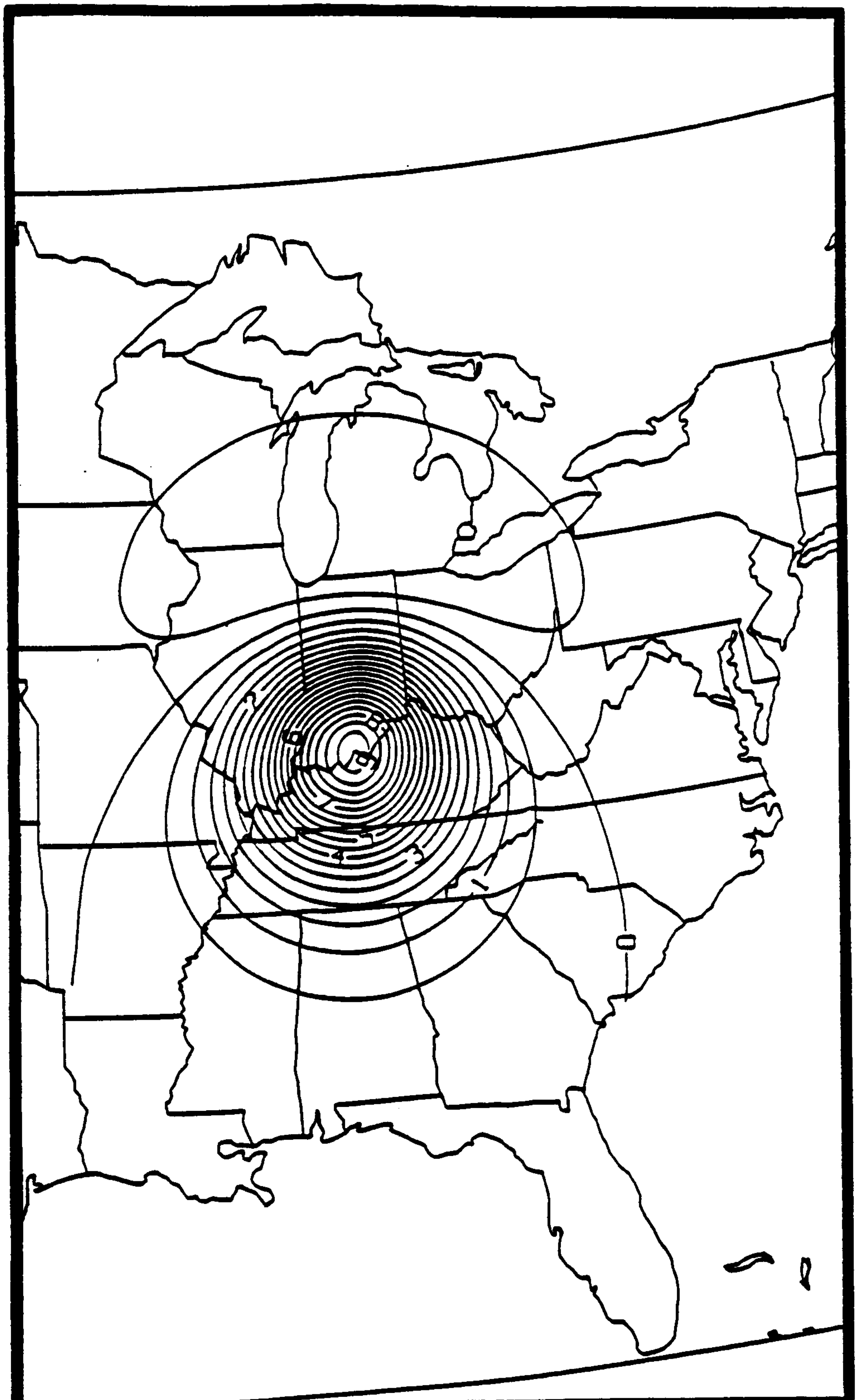


FIGURE 7

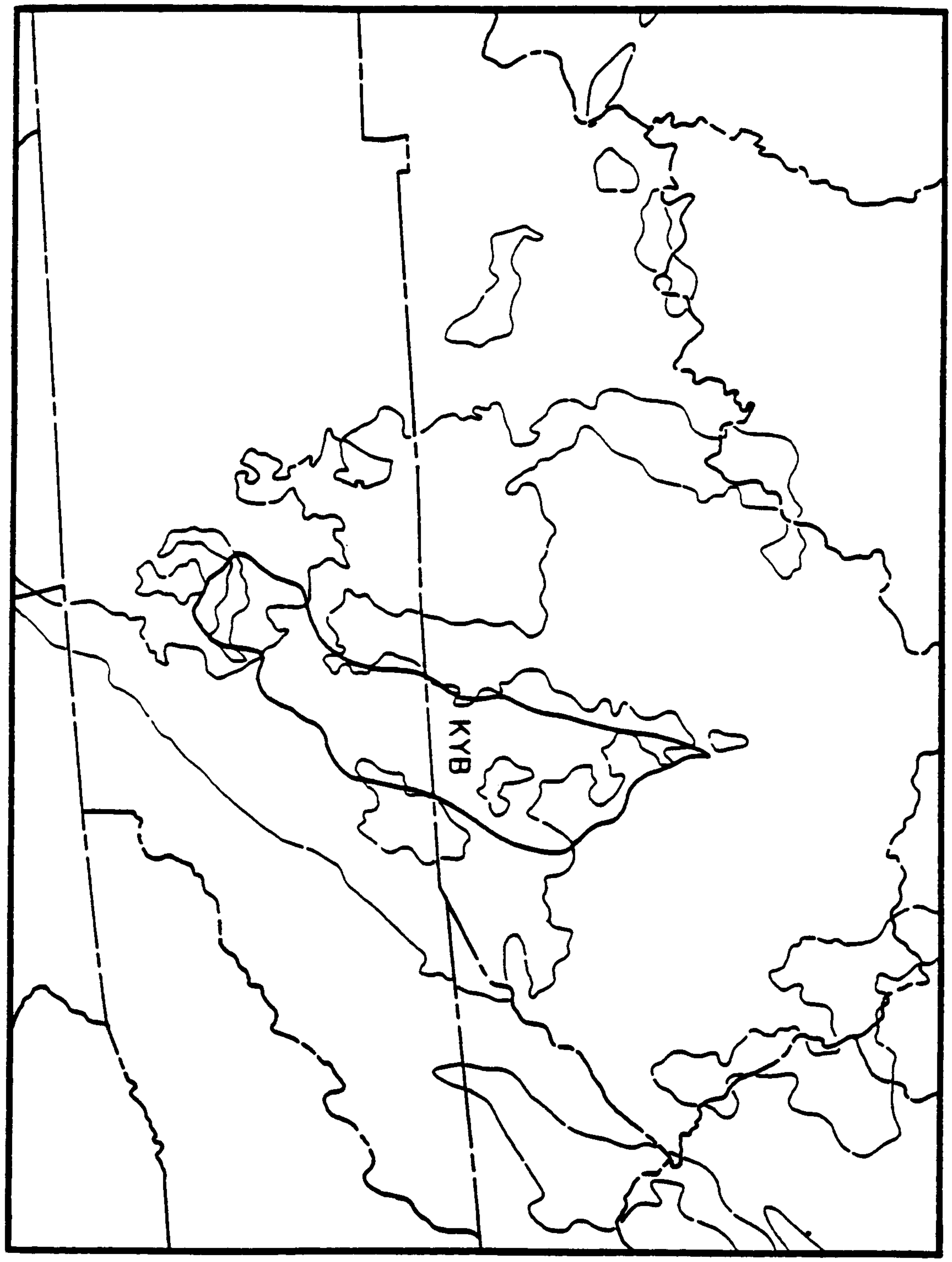
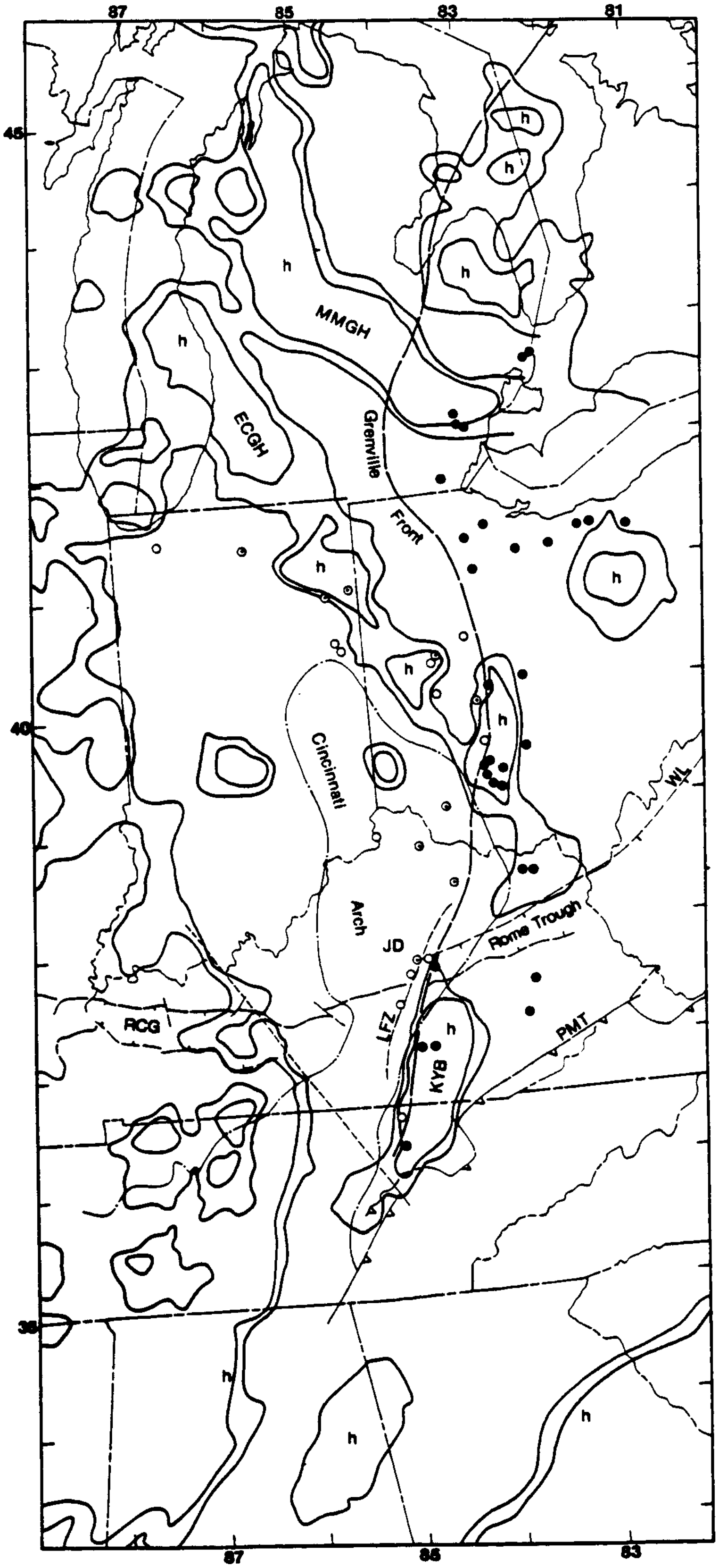


FIGURE 8



87
85
83
81
45
40
35
87
85
83
h
MMGH
ECGH
Grenville Front
Cincinnati Arch
JD
Rome Trough
WL
RCG
LFZ
KYB
PMT

FIGURE 9

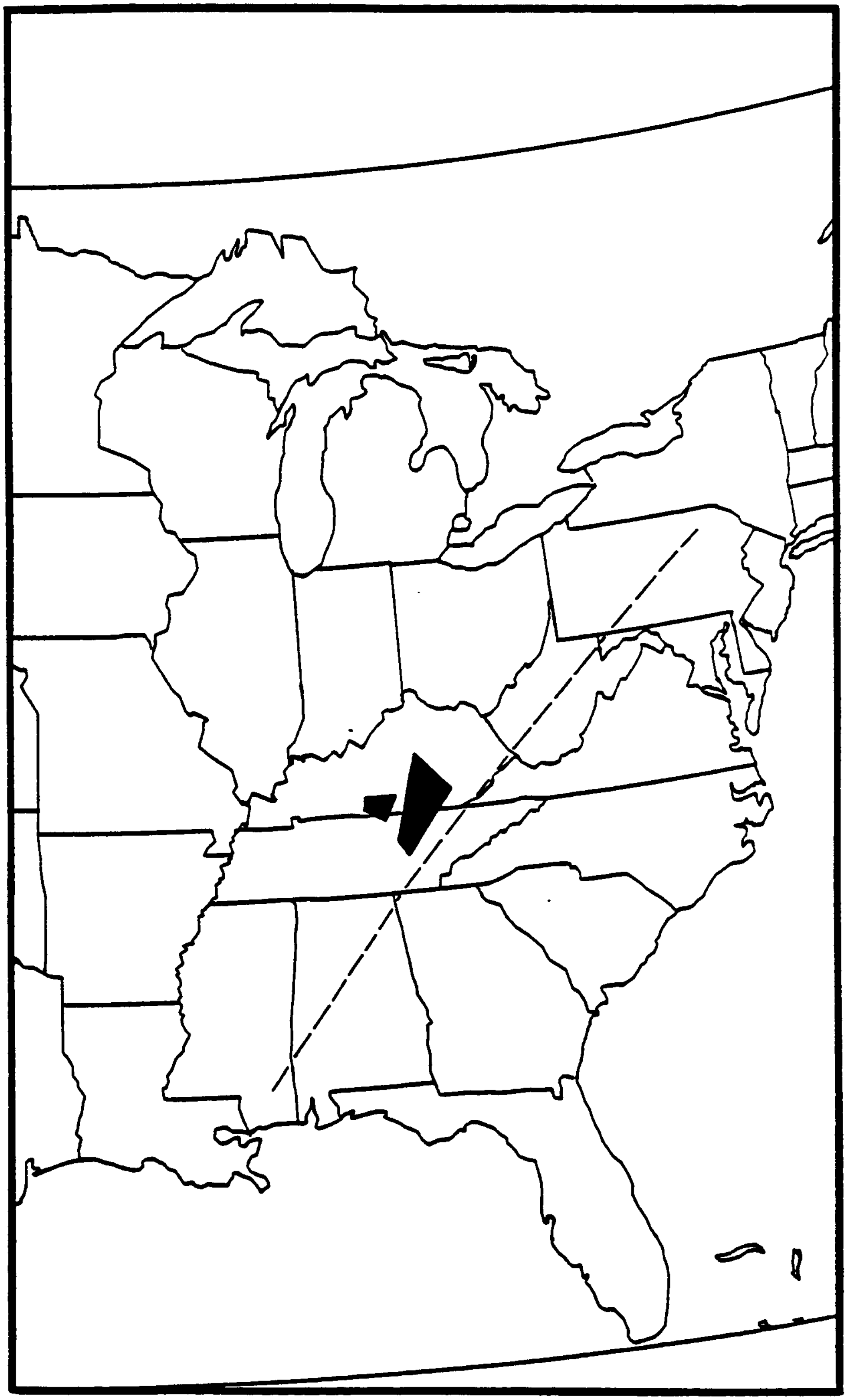


FIGURE 10

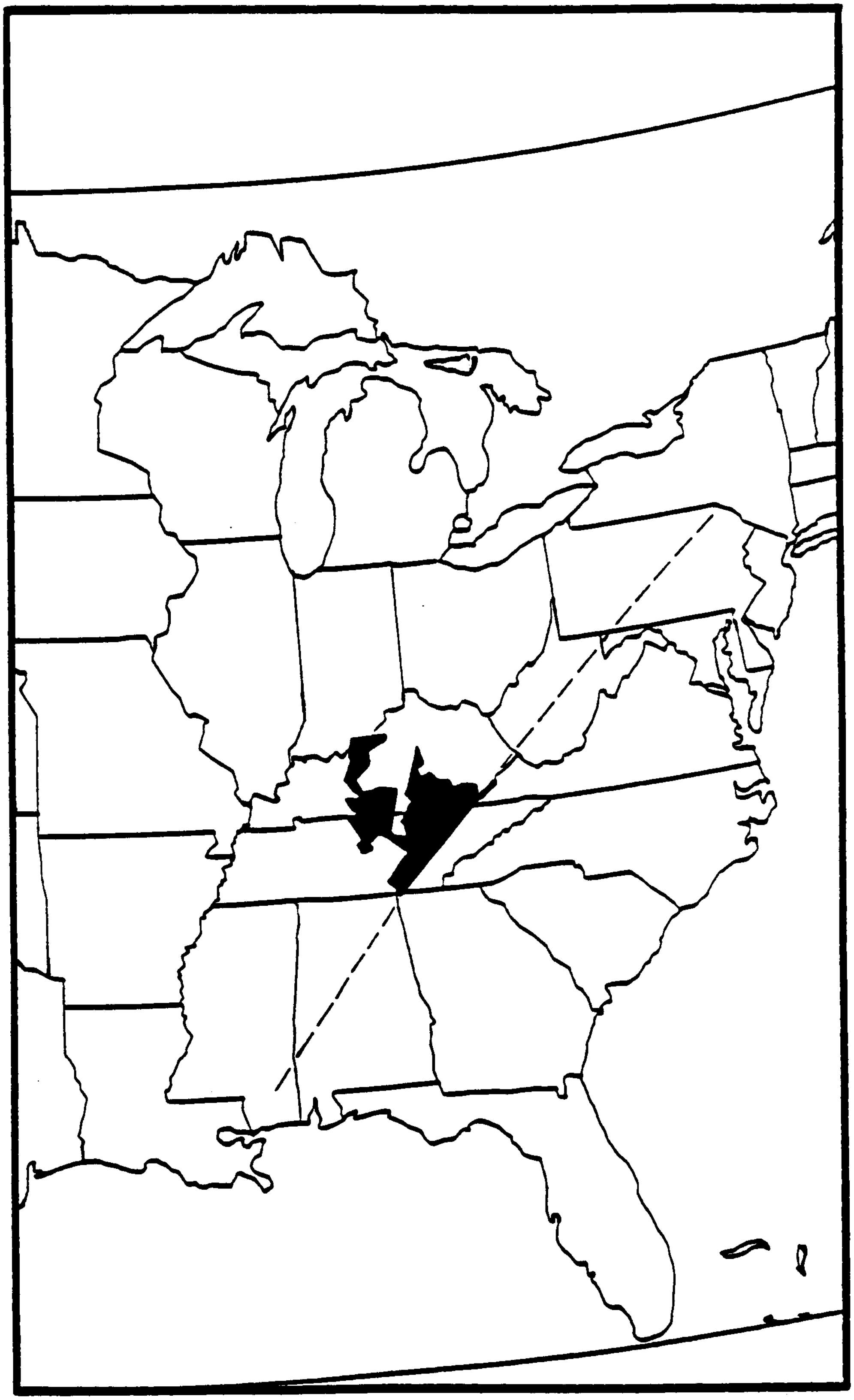


FIGURE 11

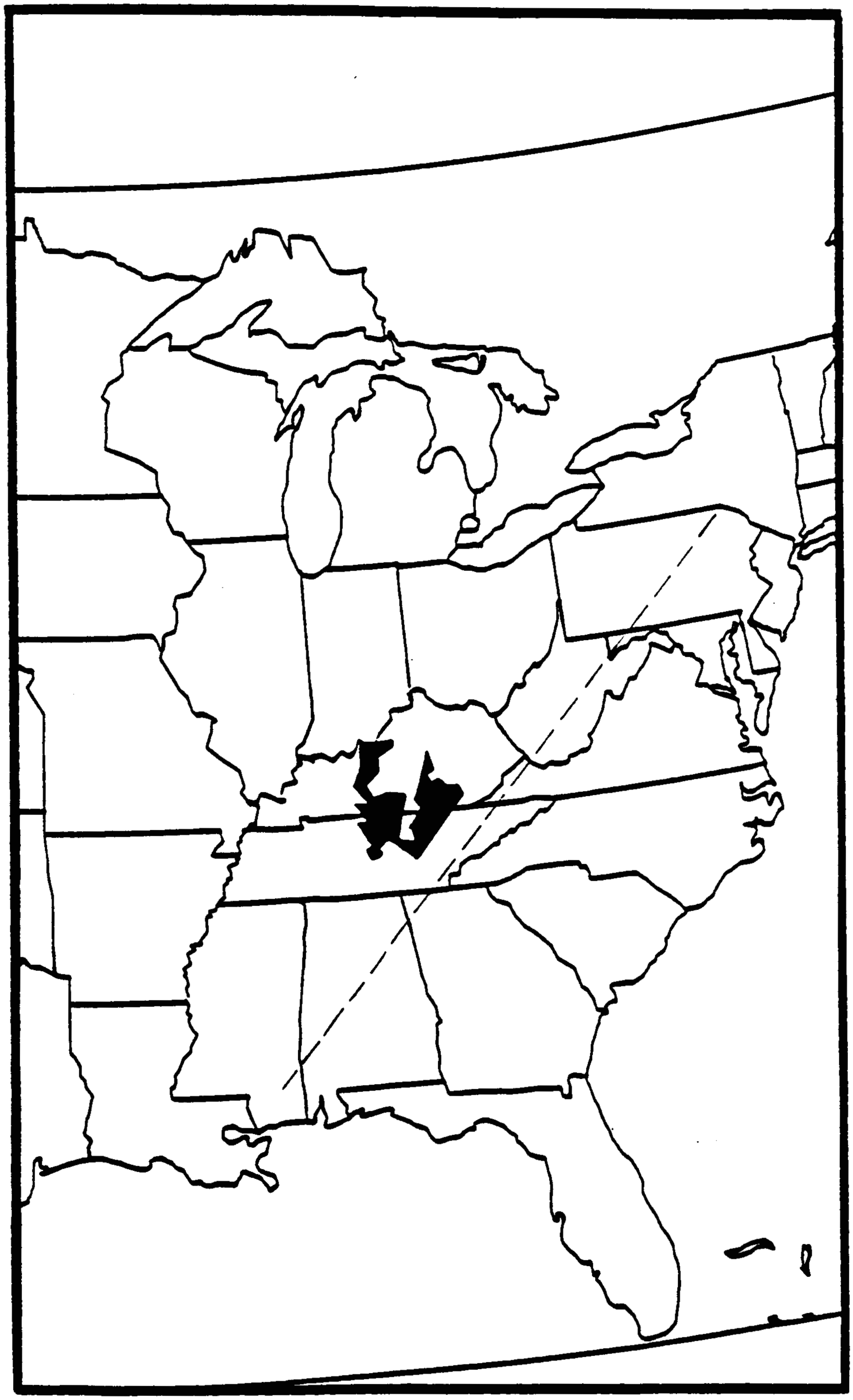


FIGURE 12

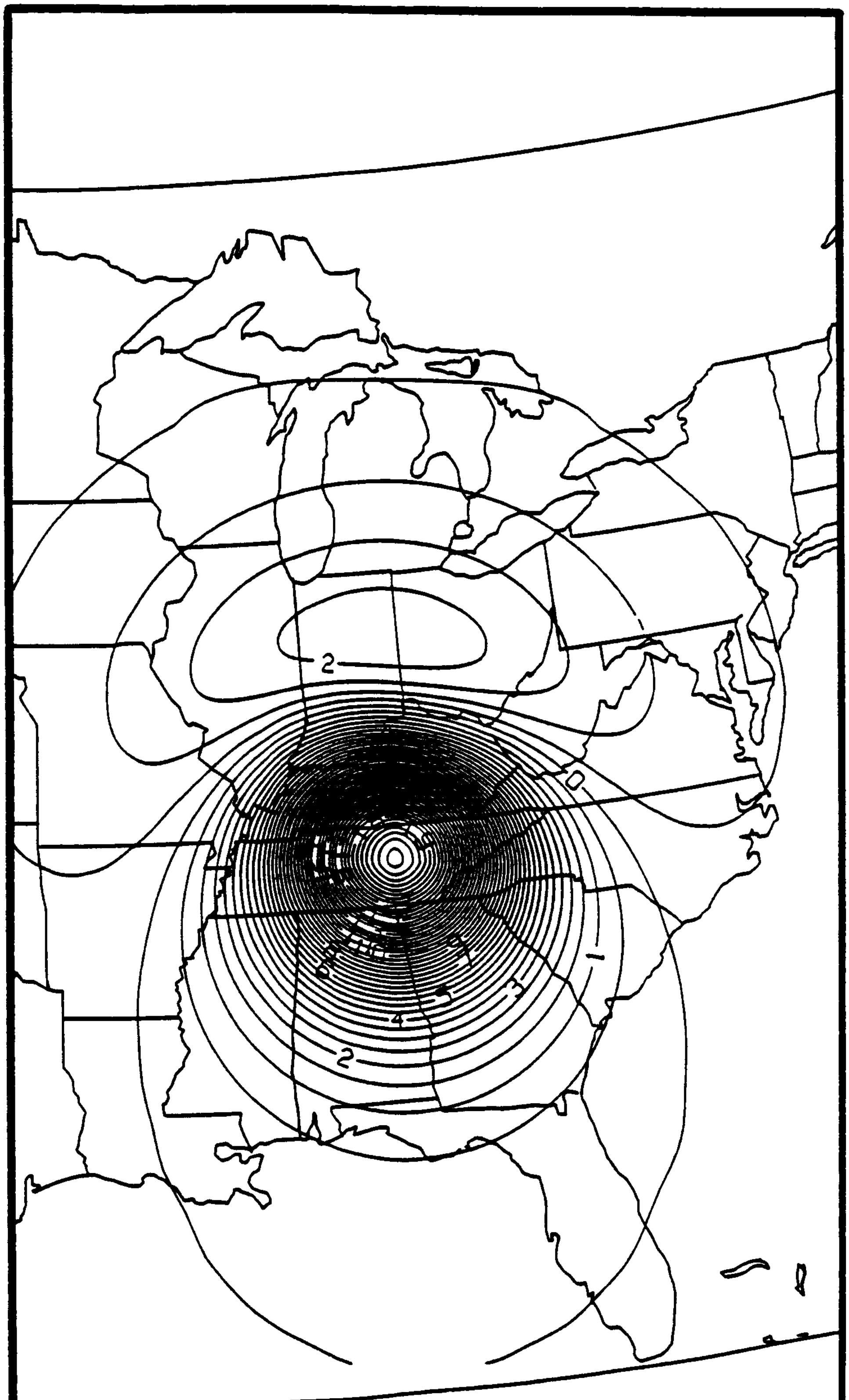


FIGURE 13

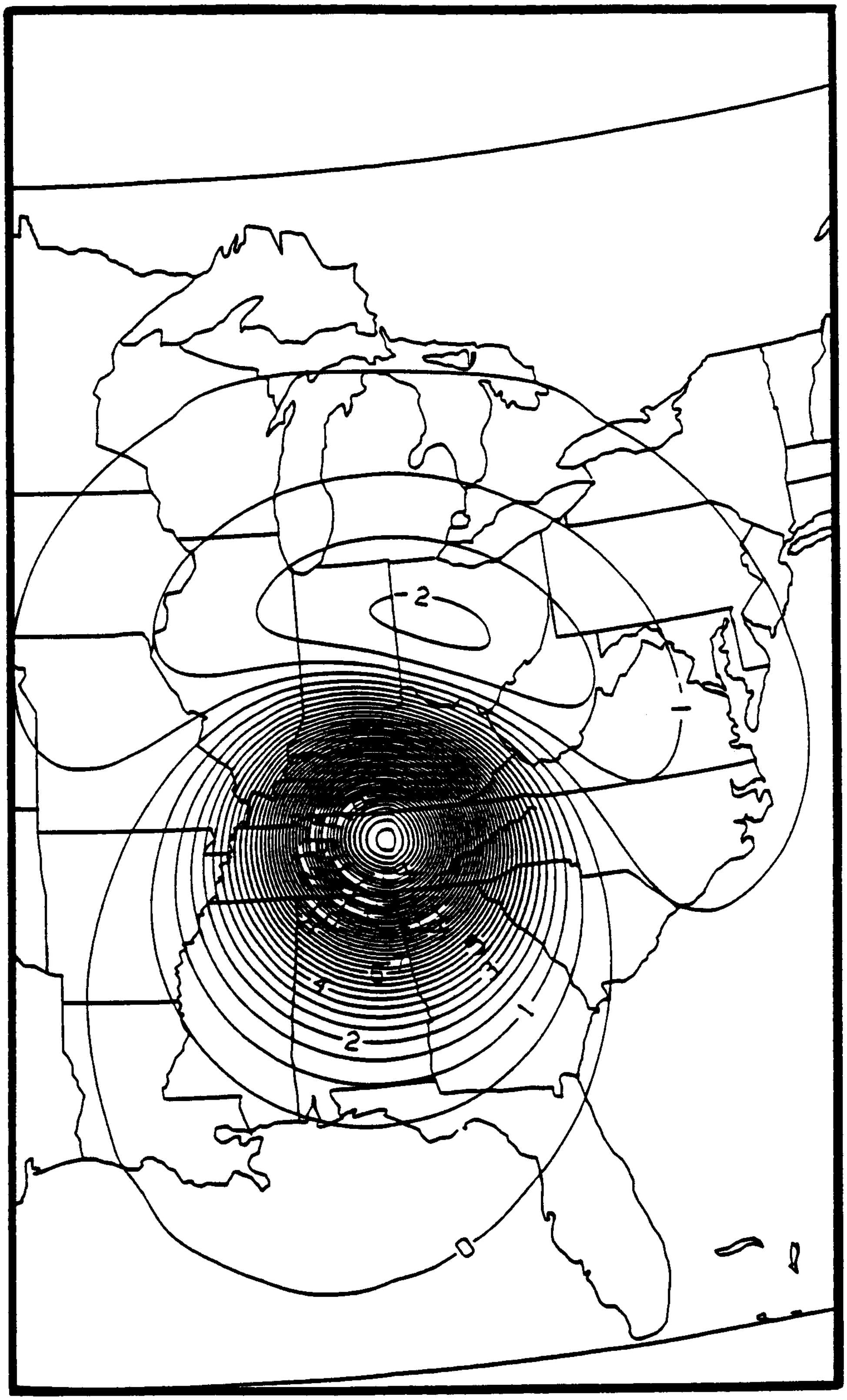


FIGURE 14

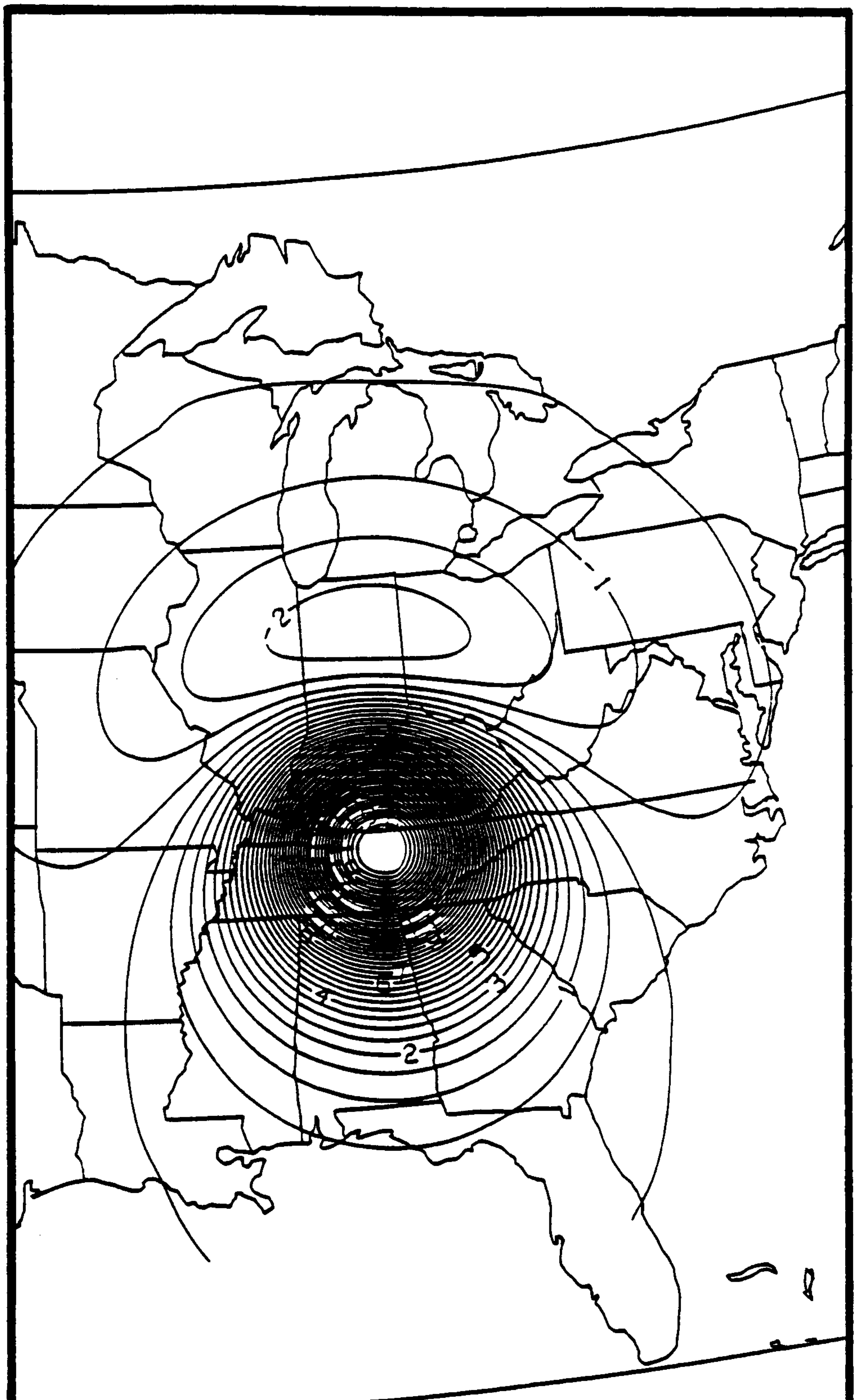


FIGURE 15

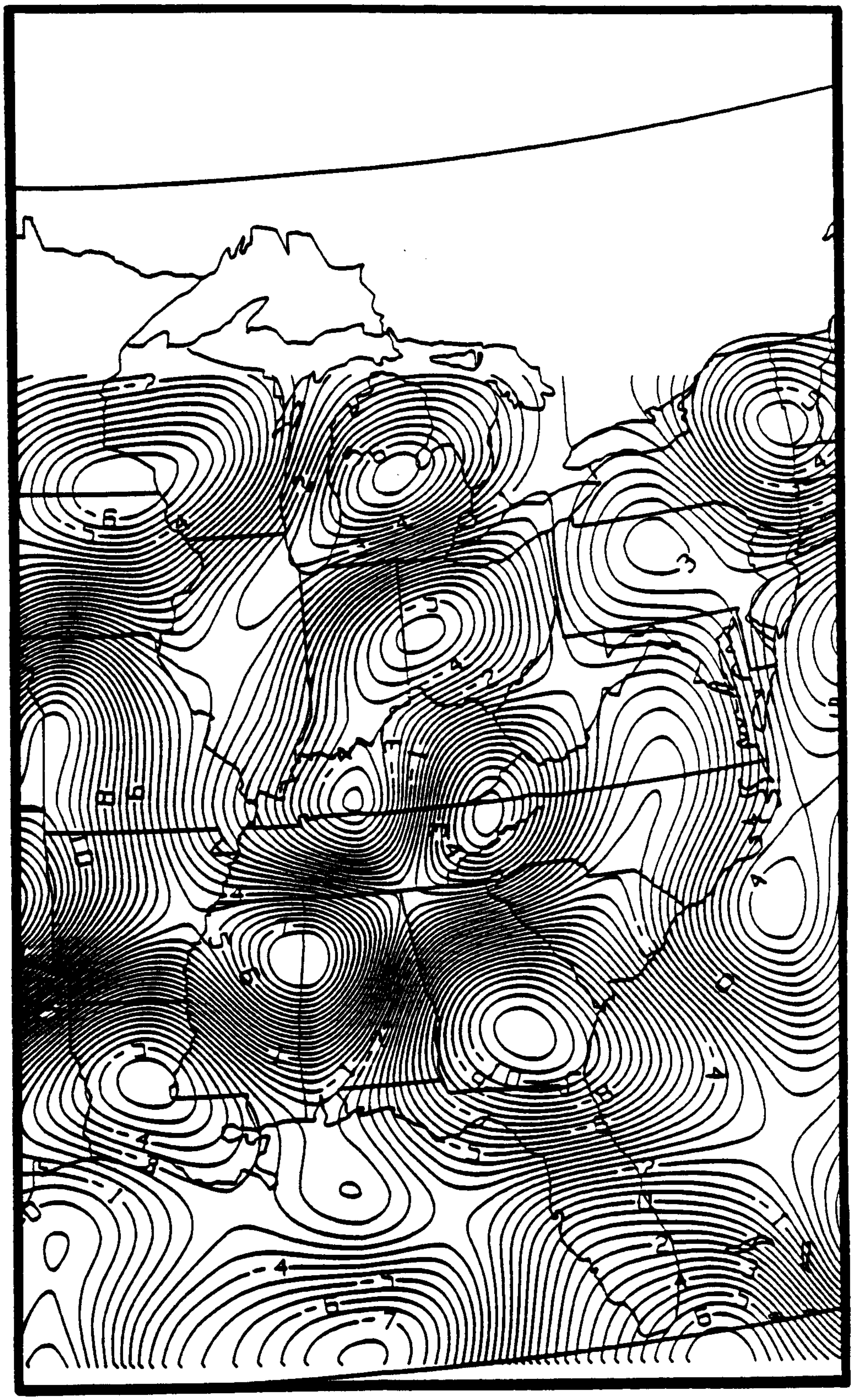


FIGURE 16

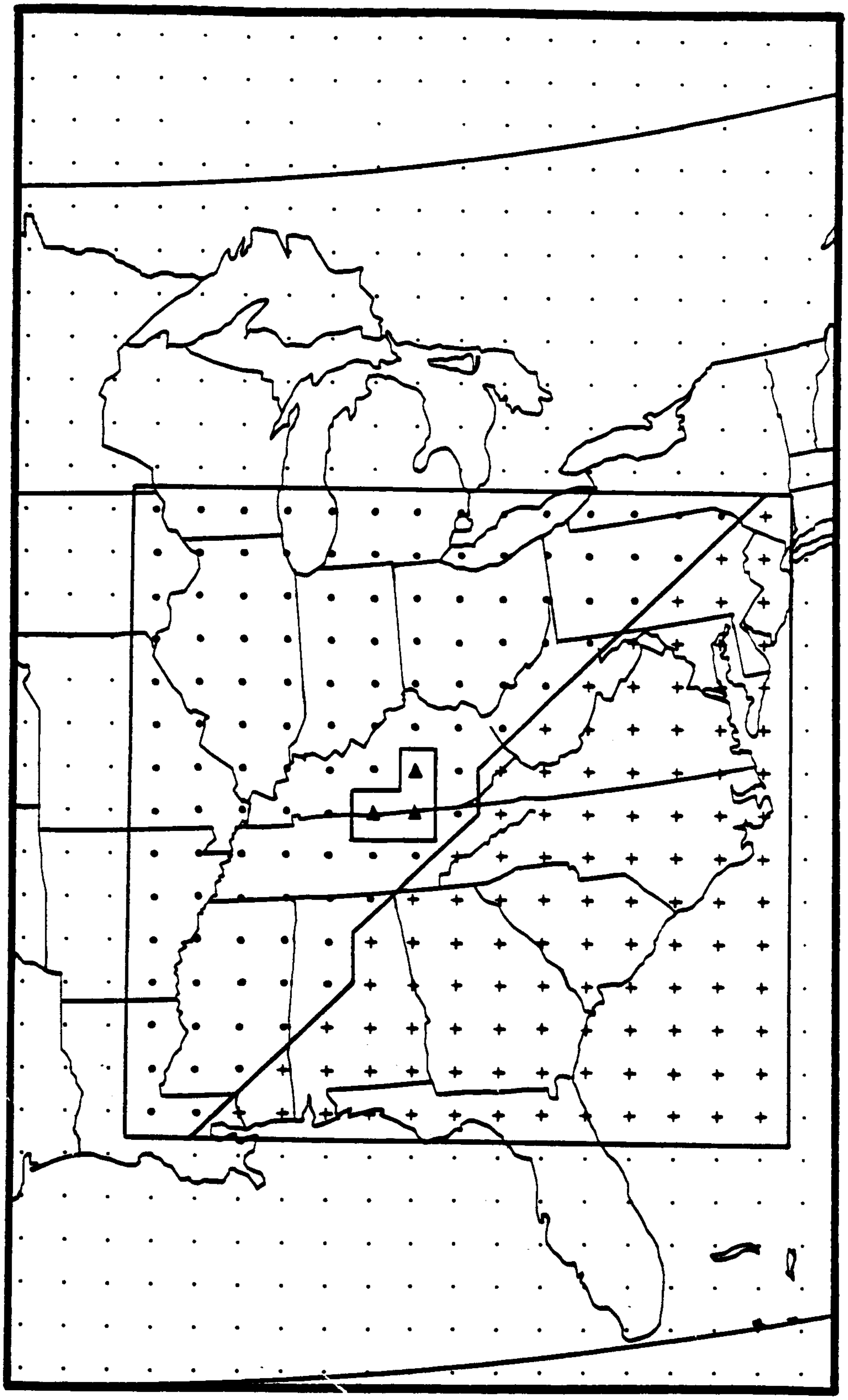


FIGURE 17